T.C.
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PRODUCTION OF SHIELD PANELS WITH POLYMER COMPOSITES AND INVESTIGATION OF MECHANICAL PROPERTIES

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ÖZET

Polimerik Malzemelerden Zirh Plakasi Üretimi Ve Mekanik Mukavemetlerinin İncelenmesi

Fiber takviyeli polimer kompozitler, yüksek spesifik mukavemet ve modülü için farklı uygulamalarda uzun süredir baskın bir rol oynamıştır. Özellikle kompozitler pultrüzyon, el yatırması, sprey ve açık kalıplama üretim tiplerine göre sınıflandırılır. Bu çalışmada, E tipi cam elyaf/reçine kompozit levhaları toz bağlayıcılı kırpıntı elyaflı mat elyaf ve fitil kullanılarak levha kalıplama bileşimi tekniği ile üretilmiştir. Levha kalıplama bileşimi hazırlamada doymamış polyester, vinil ester ve epoksi reçinesi farklı reçine türleri olarak kullanılmıştır. Epoksiden ilk başarılı SMC üretiminin gerçekleştirilmiş olması bu çalışmaya ayrıca bir yön vermiş olup epoksi reçinesini SMC'de yaygın olarak kullanılan doymamış polyester ve vinil ester reçinelerine göre alternatif olarak kullanılması bu çalışmada araştırılmıştır. Üretimler fabrika boyutunda gerçekleştirilmiştir. Üretilen ürün yüksek mekanik mukavemetli bileşim (HMC) olarak adlandırılmıştır. HMC'nin mekaniksel, fiziksel ve balistik performansını belirlemek için deneysel bir çalışma gerçekleştirilmiştir. Reçine tiplerini karşılaştırmak için 450 g/m^2 toz bağlayıcılı kırpıntı elyaflı mat elyaf üzerinde yüz 2400 teks fitille ve üçlü reçine sistemleri ile yapılan HMC'nin mekanik özellikleri ölçülmüştür. Özellikle, eğilme mukavemeti, kopma mukavemeti ve modülü sıcak kalıplama plakası üzerinden reçine özelliklerinin etkilerini değerlendirmek için ölçülmüştür. Epoksi reçine ile yapılan HMC' nin mekaniksel özellikleri diğerlerinden daha yüksek olarak bulunmuştur. Balistik test sonuçları HMC zırhlarının 435 m/s hızlarında ki 9 mm mermi parçacığına balistik direnç gösterdiğini ortaya koymuştur. Kompozitlerde ki genişleme etkileri sonra değerlendirilmiştir. Sonuç olarak doymamış polyester vinil ester ve epoksiden yapılmış HMC zırhları balistik tehditlere ve potansiyellere karşı seviye 3A kalkan malzemesi olarak kullanılma kapasitesine sahiptir.

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ABSTRACT

PRODUCTION OF SHIELD PANELS WITH POLYMER COMPOSITES AND INVESTIGATION OF MECHANICAL PROPERTIES

Fiber-reinforced polymer composites have played a dominant role for a long time in a variety of applications for their high specific strength and modulus. Especially, composites are classified via production types such as pultrision, wet lay up, spray up and molding. In this study, E-glass/resin composite laminates using powder-bond chopped-strand mat and fibers were fabricated using sheet molding compound technique. In preparation of the sheet molding compounds unsaturated polyester, vinyl ester and epoxy were chosen as resin types. Epoxy as being successfully used for the first time in SMC gave a new perspective that can be used as an alternative method to unsaturated polyester and vinil ester resins, which are very widely used in industry, was investigated in this study. Productions were carried out in fabrication process. The composites were characterized as high mechanical strength compound (HMC). An experimental investigation was carried out to determine the mechanical, physical and ballistic performance of HMC. The measured mechanical properties of HMC produced with 2400 text hundred wick on 450g/m^2 powder-bonded chopped-strand mat glass fiber and resin systems were compared for the three various resin types. Especially, the flexural strength, tensile strength and modulus were compared through compressed plate in hot mold. It was found that the mechanical properties of the composites made with epoxy resin are higher than others. The ballistic test result showed that the HMC shields have ballistic resistance against 9 mm fragment simulating projectiles (FSP) up to 435 m/s projectile velocities. The extensions of damages in the composites were evaluated after impact. It was concluded that the HMC shields that made with unsaturated polyester, vinyl ester, and epoxy have capacity against the ballistic threats and potential to be used as shield materials level IIIA.

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SYMBOLS

g/cm^3	Density
°C	Temperature
°F	Fahrenhayt
GPa	Giga Pascal
MPa	Mega Pascal
kPa	Kilopascal
η^0	Viscosity
g	gram
Ge	Equilibrium Modulus
m.p	Melting Point
wt.%	Weight Ratio
E	Elastic modulus
σ	Tensile Strength
MN/m	Specific Modulus
MN/m/kg	Spesific Strength
µm/C°/10-5	Coefficient thermal expansion
mm	Millimeters
µ	Micron
µm	micrometer
h	Hour
min	minute
sec	second
cp	centipouse
mm/min	Speed
σ_f	the flexural stress, in megapascals (Mpa)
F	Load in Newtons (N);
L	Length (mm)
h	Thickness (mm)
b	Width (mm)
E_f	Flexural modulus of elasticity (MPa)
Δs	Difference in deflection between s” and s’
ΔF	Difference in load F” and load F’ at s” and s’

s” and s’	Beam mid-point deflections, in millimeters (mm)
inc	inch
ft	Foot
N/mm^2	Newton/millimetre
Kj/m^2	Kilojoule persquare
σZB	Max Strength Force

ABBREVIATION

RTM	Resin Transfer Method
VARTM	Vacuum Assisted Resin Transfer Molding
FSPs	Fragment Simulating Projectiles
UP	Unsaturated Polyester
HDT	Heat Deflection Temperature
VE	Vinyl Ester
UD	Unidirectional Composites
GRP	Glassfiber Reinforced Plastic
HMC	High Mechanical Properties
SMC	Sheet Molding Compund
BMC	Bulk Molding Compound
FRP	Fiber Reinforced Plastics
PVAc	Polyvinylacetate
ATH	Aluminium Tri Hidrate
AP	Armor Piercing
LRHV	Long Rifle High Velocity
FMJ	Full Metal Jacket
RN	Round Nose
JSP	Jacketed Soft Point
SWC	Semi-Wadcutter
PA/PE	Polyamide/Polyethylene
BSE1152	DSM Dewilux 511-950 + DSM palapreg H 852
BSE1180	DSM Dewilux 511-950 + DSM palapreg H 1080
BSE1052	DSM ATLAC XP 810 + DSM palapreg H 852
BSE1080	DSM ATLAC XP 810 + DSM palapreg H 1080
BSE7352	DSM PALAPREG 2273 + DSM palapreg H 852
BSE7380	DSM PALAPREG 2273 + DSM palapreg H 1080
ASTM	American Society for Testing and Materials
ISO	International Standard Organization
TSE	Turk Standard Institute

IEC	International Electrotechnical Commission

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CHAPTER 1: INTRODUCTION

It is becoming increasingly difficult to meet the material needs of the ever advancing technology with traditional means. Metal based traditional materials are being replaced with composites, semiconductors, and plastics in the applications of newly developed technologies. Polymer composites are being used in increasing quantities in diverse fields, e.g., aerospace, automotive, electrical, microelectronic, infrastructure and construction, medical, and chemical industries, as a result of improved material performance, cost-effective production, and manufacturing flexibility (especially the thermoplastics) [2,3]. In parallel to such advances in the composite materials throughout the world, particularly polymer composites rapidly found technological applications in our country [4].

Polymer composites can be manufactured with desirable physical and chemical properties that include high specific stiffness and strength, dimensional stability, temperature and chemical resistance, and relatively easy processing. Such control properties play an important role for their cost effectiveness in industrial applications and meeting the needs of material science and technology to design and produce new and more reliable technological applications [5-6].

The needs of airline and space industry may be looked at as one of the driving forces for the speed in the research and technological applications of composite materials with properties of low weight, high mechanical and heat resistance [7]. Additionally, bulletproof jackets are also being produced from various polymer composites [8].

Weight reduction of the armor system brings the mobility and transportability. Traditional single component armor systems such as steel, aluminum, titanium and ceramic are not the most effective one against the ballistic threat. As backing plates, glass fibers (S-2 glass, E-glass) are being employed with epoxy, vinyl ester and polyester resin systems due to their high tensile and compressive strength, good energy absorption properties and relatively lower costs [9].

Sheet molding compound technique has many advantages over other manufacturing processes which are resin transfer molding (RTM), pultruzyon and vacuum assisted resin transfer molding (VARTM), including high fiber volume fraction, high production capacities, lower production costs.

It is aimed to investigate the production of shield panels from various composites materials using advanced engineering polymers, which are more stronger and lighter than steel, with reinforced diverse fibers.

The produced shield panels in this study is planned to be used in land, air and navy force defense industries. The major purpose in this study is to produce shield panels that are low weight, flame resistance, and bulletproof. Consequently, with the low weight composite panels, the ability to move easily will not be hard like the traditional bulletproof coatings. Moreover, the use of these advanced materials increases the protection levels.

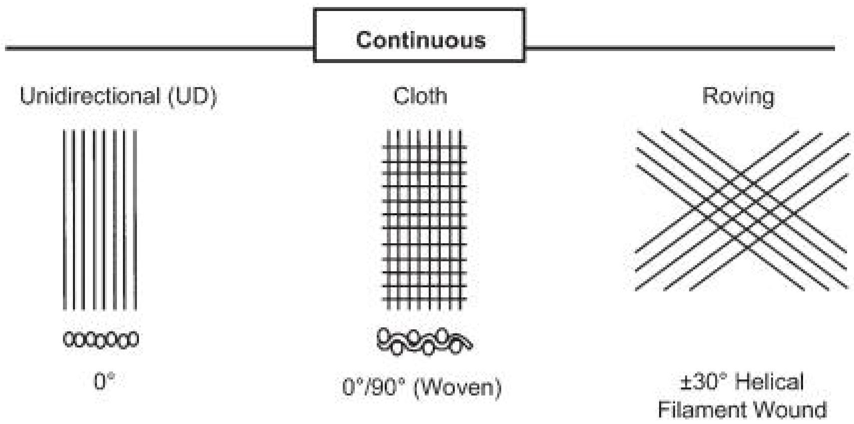
Advances of the research and development with the polymer composite technology in defense industry will increase the Turkish Composite Industry market growth. Moreover, the suppliers of these composites will recognize income growth and consequently improve the national economy.

In the present work, the composites shields were manufactured using sheet molding compound technique. Evaluating the mechanical properties at different conditions, flame resistance was performed. In addition the ballistic test was performed using fragment simulating projectiles (FSPs) to determine the ballistic properties. After the ballistic tests some of composite shield were classified to the damaged zones to different impact velocities.

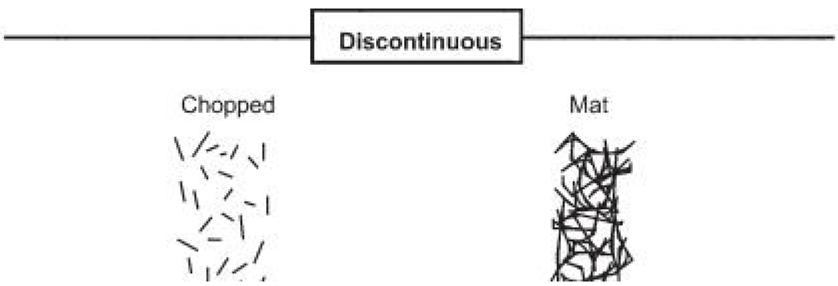
CHAPTER II: COMPOSITES

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone [10]. In addition, Individually is not suitable for the desired purpose of two or more different to provide the desired properties of the material terms and rates of specific physical in a macro-structure composite material is obtained by bringing together [11].

Composite materials consist of reinforced components and resin (matrix). The reinforcing phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger, and stiffer than the matrix. The reinforcement is usually a fiber or particulate [10]. Examples of continuous reinforcements include unidirectional, woven cloth, and helical winding (figure II.1.a), while examples of discontinuous reinforcements are chopped fibers and random mat (figure II.1.b) [10].



a) Continuous reinforcement



b) Discontinuous reinforcement

Figure II.1 : Typical Reinforcement types

The continuous phase is the matrix, which is a polymer, metal or ceramic. Polymers have low strength and stiffness, metals have intermediate strength and stiffness but high ductility, and ceramics have high strength and stiffness but are brittle.

The reinforcement type and the matrix affect processing. The major processing routes for polymer matrix composites are shown in fig 2.2 [10].

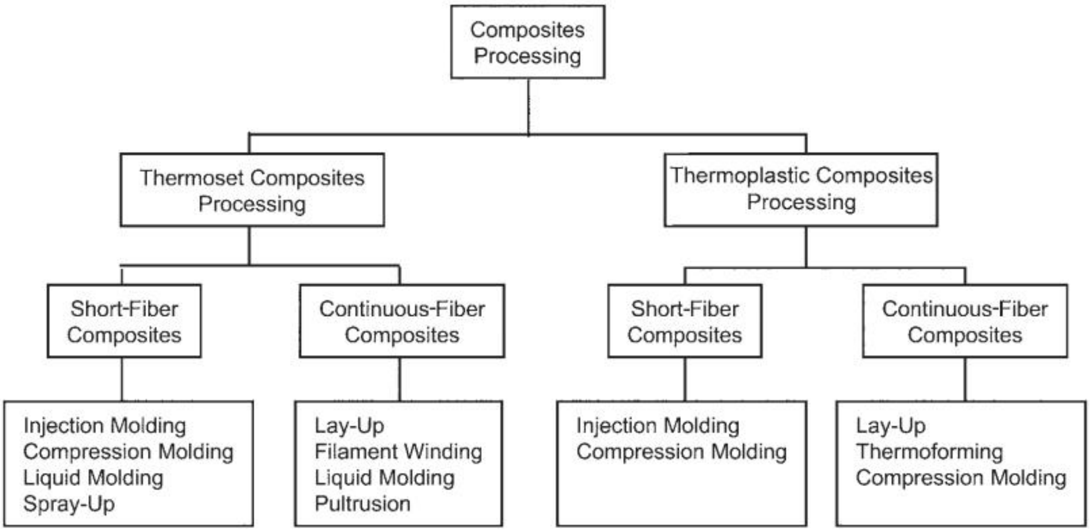


Figure II.2 : Major polymer matrix composite fabrication process

II.1 Advantage and Disadvantage of Composite Materials

Composite materials have gained importance according to metal materials due to differences of the properties of composites materials according to the metal. Low density of composites provides advantages in structures. In addition, reinforced fibers composite materials ensure advantages for corrosion heat, sound and electrical resistance. Advantages of composites materials are mentioned below.

High Strength **:** Tensile and flexural strength of composites is higher than metal material. In addition desired way and areas of tensile and flexural strength is accorded due to properties of molding.

Shaping **:** Large and complex composite parts molded in one piece. It provides benefits from material and time.

Electrical Properties : Having superior electrical properties composites are obtained as choosing proper materials. Composites can be used as a insulator or conductive material on transfer line.

Resistance of Corrosion And Chemical Effect **:** Composites are not damaged from air effect, corrosion and many of chemical substances. For this reason composites can be used as chemical tank, tube, exhauster, boat and other marine vehicles in safety.

Resistance of Fire and Heat **:** Low heat transfer coefficient provides to use under high heat resistance applications.

Coloring **:** Resins are compatible with pigment paste. Desired pigments are added in mixing paste processing and composites are molded without pigmentation [11].

Disadvantages of composite include high raw material costs and usually high fabrication and assembly cost; adverse effects both temperature and moisture; poor strength in the out of plane direction where the matrix carries the primary load susceptibility to impact damage and delaminations or ply separations; greater difficulty in repairing them compared metallic structures [10]. In addition, tensile, flexural and impact strength values are variable in same composites materials. Composite materials show different mechanical properties in different directions [11].

II.2 Applications of Composites

Applications include aerospace, transportation, construction, marine goods, sporting goods and more recently infrastructure with construction and transportation being the largest [10]. Composites are designed to achieve unique thermo-mechanical properties and superior performance characteristics, not possible with traditional materials. The need for high strength, high stiffness and light weight materials for structural applications has increased the use of composites in high performance applications in aircraft, land based vehicles and amour (Figure II.3a) [12].

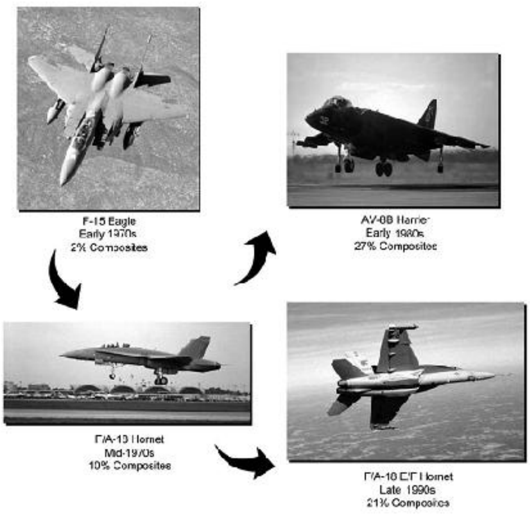


Figure II.3 a) Typical fighter aircraft applications (Source: the Boeing company)

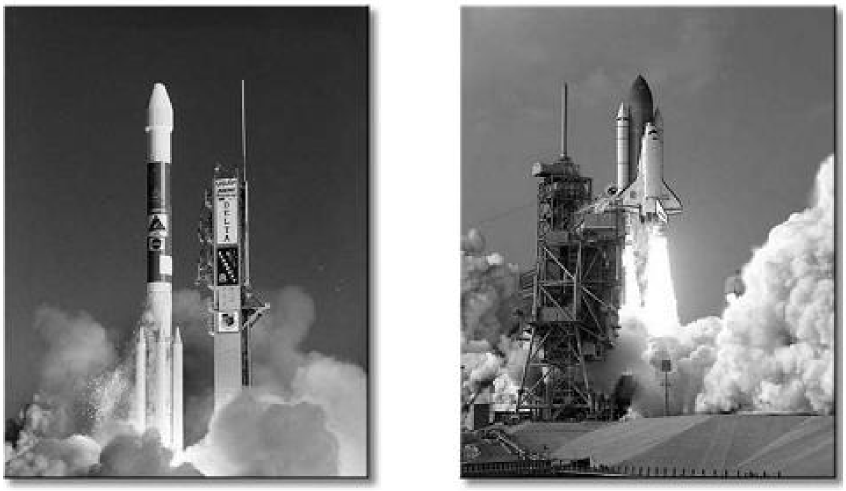


Figure II.3a Space Aircraft Structure

The major automakers are increasingly turning to composites to help them meet performance and weight requirements, thus improving fuel efficiency. The product from is typically fiberglass sheet molding compound made by compression molding (Figure II.3b)

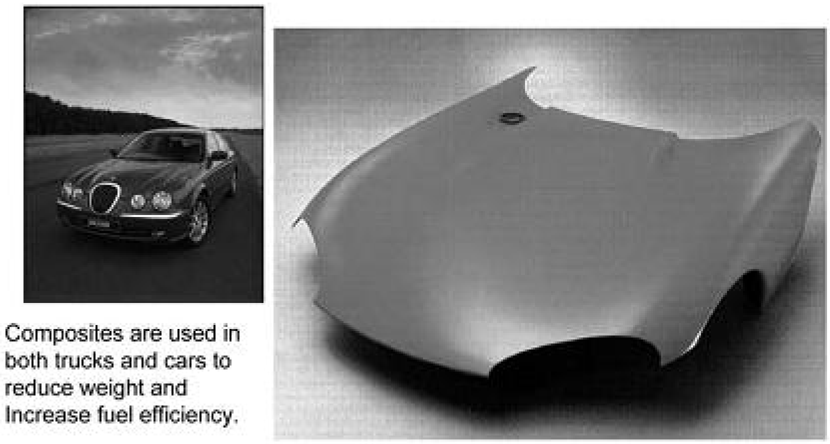
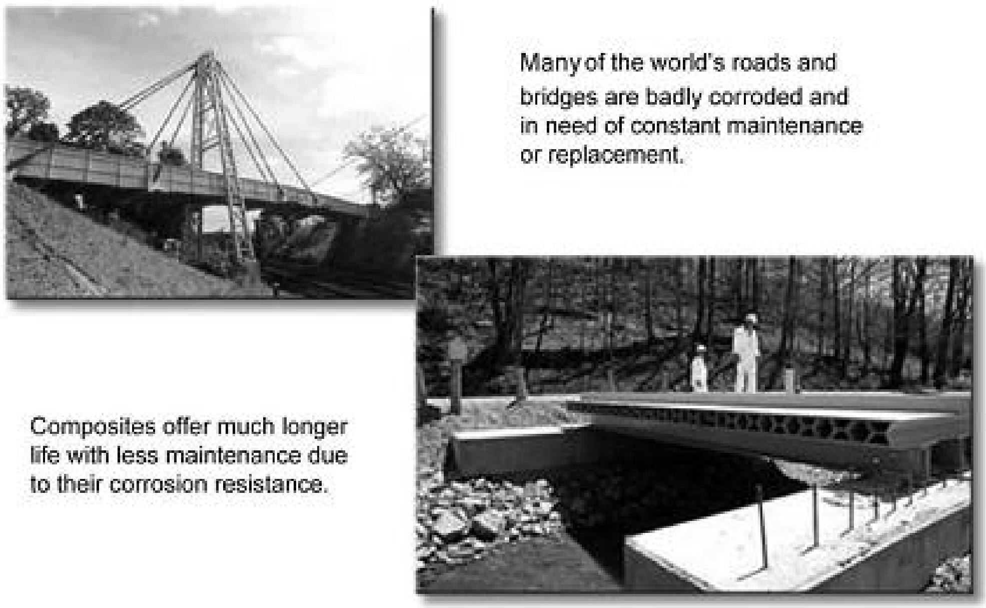


Figure II.3b Transportation Applications

Corrosion is a major problem for the marine industry. Composites help minimize these problems, primarily because they do not corrode like metals or not like wood. Hulls of boats ranging from small fishing boats to large racing yachts are made of glass fiber and polyester or vinyl ester resins (Figure II.3c).

Figure II.3c Marine Applications

Using composites to improve the infrastructure (Figure II.3d) of our roads and bridges is a relatively new, exciting application. Typical Process /materials include wet lay-up repairs and corrosion-resistant fiberglass pultruded products.



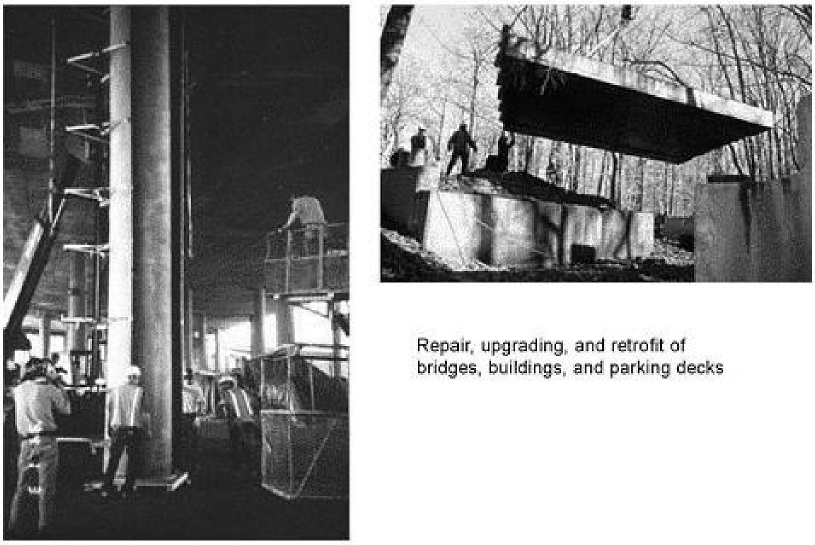


Figure II.3d Infrastructure Applications

In construction (Figure II.3e), pultruded fiberglass rebar is used strengthen concrete, and glass fibers are used in some shingling materials [10].

Figure II.3e Construction Applications.

Wind power is the world's fastest-growing energy sources. The blades for large wind turbines (Figure II.3f) are normally made of composites to improve electrical energy generation efficiency.

Figure II.3f Composites Clean Energy Generation

The predominant material is continuous glass fibers manufactured by either lay up or resin infusion. Tennis racquets (Figure II.3g) have been made of glass for years, and many golf club shafts are made of carbon. Processes include compression molding for tennis racquets and tape wrapping or filament winding for golf shafts. Lighter, stronger skis and surfboards also are possible using composites. Another example of composite application that takes a beating yet keeps on performing is a snowboard, which typically involves the use of a sandwich construction for maximum specific stiffness [10].

Figure II.3g Sporting Goods Applications

II.3 Classification of Composites

Composites are classified two categories which are matrix and reinforced structures.

II.3.1 Matrix Structures

Matrix has three basis functions in composite structures. These are, keeping together fibers, distributing load to fiber and protecting environmental impact fibers [13]. In addition, structure of matrix provides plasticity and ductility superior [14]. Matrix is classified in three groups which are polymers, metals and ceramics. They have poor and strong side that shown Figure II.4

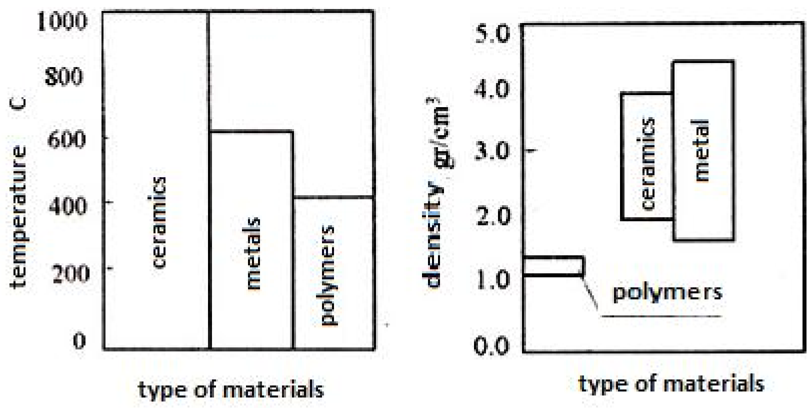


Figure II.4 Temperature and density properties of different matrix material that used in composites.

II.3.1.1 Metal Matrix

Metals are soft and low endurance in pure situation. In contrast, endurance and stiffness are developed by alloy, cold forming and heat treatment. Metals materials do not break in pushing high capacity loading, they flow and distribute all system. It provides safety in using.

In addition metals can be formed flowing easily or by deformation of plastic. Some of metals are obtained composites with reinforced fiber or particles. Metal alloys composites can resist high temperature like 1000 °C that are composed of tungsten alloys with reinforced fiber. Jet engines are made from these alloys such as the tungsten alloys [14].

II.3.1.2 Ceramic Matrix

Ceramics are low density, durable and hard they are extremely brittle. They are resistance of thermal and chemical effects. In addition they can be used as an isolator [14]. Comparing with metals, ceramics do not flow such as plastics cause of brittle. Ceramic composites is prepared from such as these ceramic matrix Li_2O_2-Al_2O_3-SiO_2, SiO_2 ve BaO-SiO_2-Al_2O_3-Si_3N_4 (with SiC). Al_2O_3, SiC, Si_3N_4 are used reinforced materials [14].

II.3.1.3 Polymer Matrix

Polymers are low density and easy to produce complex shaped parts with plastics. Some polymers have low endurance and low mechanical properties. Composite materials produced from polymer matrix rate of 90 %. There are two types' polymers that are thermoplastic and thermosets [14].

Thermoplastic

Thermoplastics are an important class of material used for many types of product. The name thermoplastic indicates that the materials can be melted and reformed into new objects by the application of heat. This distinguishes them from thermosetting plastics, which once formed, cannot be reshaped by heating. Thermoplastics are a diverse group of materials so that it is possible to select one that provides the performance needed for a particular application. Considerations include mechanical performance, aesthetics, resistance to chemicals, cost, stability to heat and recyclability to name just a few. Plastics are often perceived as cheap materials, whereas in reality the price and performance of polymers varies over a huge range and the best solution is usually the one that meets the design criteria at the lowest cost. Materials cost is just one aspect though. Often metals or other materials offer a cheaper solution if compared to plastic. However, the design flexibility that plastics offer allows the integration of several parts and the resultant reduction in complexity and assembly costs is what may make the use of plastic a better overall solution [15].

Thermosets

Thermosets are network-forming polymers. They include epoxy, phenolic, unsaturated polyester, polyurethane, dicyanate, bismaleimide, acrylate and many others. Unlike thermoplastics, chemical reactions are involved in their use. As a result of these reactions the materials first increase in viscosity and eventually cross-link and become set, and as a result they can no longer flow or dissolve. Cure is most often thermally activated, which gives rise to the term thermoset, but network-forming materials whose cure is light activated are also considered to be thermosets. Some thermosetting adhesives cross-link by a dual cure mechanism that is by either heat or light activation.

In the uncured state thermosets are mixtures of small reactive molecules, often monomers. Catalysts are often added to accelerate cure. Most thermosets incorporate particulate fillers or fiber reinforcement to reduce cost, to modify physical properties, to reduce shrinkage during cure, or to improve flame retardance. Thermosets generally possess good dimensional stability, thermal stability, chemical resistance and electrical properties. Unlike thermoplastic polymers the processing of thermosets includes the chemical reactions of cure. As illustrated in Figure II.5 cure begins by the growth and branching of chains. As the reaction proceeds, the increase in molecular weight accelerates, causing an increase in viscosity, illustrated in Figure II.6, and reduction in the total number of molecules [16].

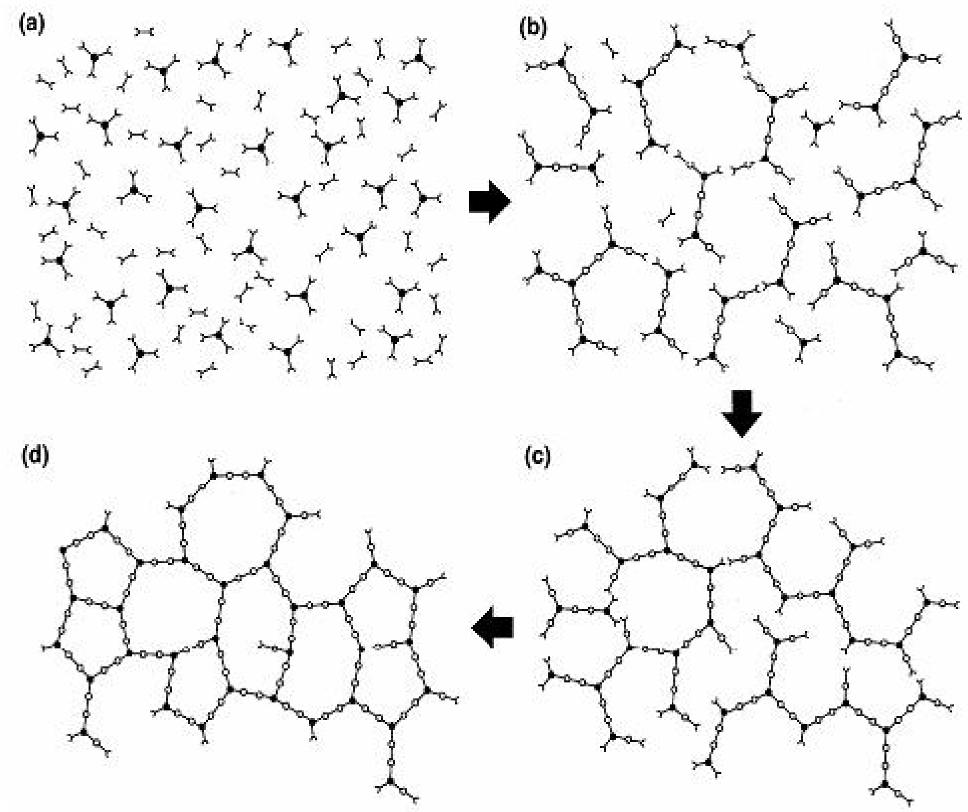


Figure II.5. Schematic, two-dimensional representation of thermoset cure. For simplicity Di functional and tri functional co-reactants are considered. Cure starts with A-stage or uncured monomers and oligomers(a); proceeds via simultaneous linear growth and branching to an increasingly more viscous B-stage material below the gel point (b); continues with formation of a gelled but incompletely cross-linked network (c); and ends with the fully cured, C-stage thermoset (d).

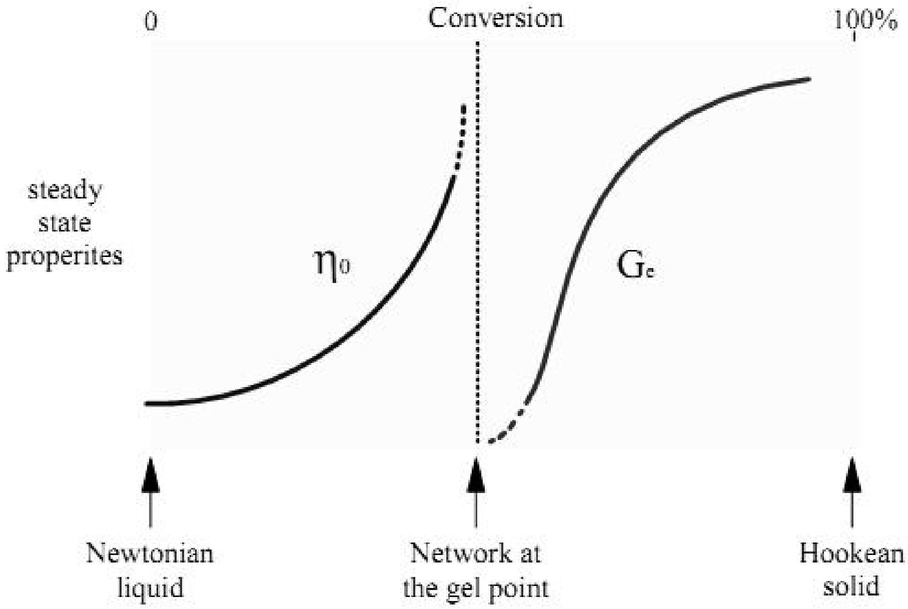


Figure II.6. Macroscopic development of rheological and mechanical properties during network formation, illustrating the increase in viscosity η, which tends toward infinity at the gel point; the first appearance of an equilibrium modulus Ge, at the gel point; and the increase in modulus with completion of the network.

Unsaturated Polyester

Unsaturated polyester (UP) resins are versatile plastics used a wide variety of applications [17]. Unsaturated polyester resins cure by a free-radical mechanism. The high free-radical flux needed to cure the thermoset resins can be generated under many conditions: room temperature, heat, UV light, or visible light, provided the appropriate free-radical initiator is used [18]. Polyesters occurred as a result of dicarboxylic acid and polyhydric alcohols polymerization of condensation. In addition, unsaturated polyester contains maleic anhydride or fumaric acid as the dicarboxylic acid component such as unsaturated [19]. Polymer, as a product, is solved in reactive styrene monomer to compose matrix structure and get low viscosity liquid. When the resin hardened, it reacts with the unsaturated ends of polymer monomer and converts solid thermoset structure.

The necessary material to produce polyester is listed below.

a) Glycol
b) Unsaturated dibasic acid
c) Saturated dibasic acid,
d) Reactive monomer
e) Inhibitor

a) Glycol

The basic glycol is ethylene glycol. It is used the production of polyester, but it gives tendency to crystallization the product and incompatible with styrene monomer. For this reason, glycol is used with another glycol or can be provided acetyl or propionyl group in resins. Unsaturated polyester provides to crosslink inside polyester. The high rate of use, the higher of the degree of cross-link utilization increase. In addition, increase in this rate increases deflection heat temperature (HDT). Also it may cause to decrease of tensile and elongation of break values. This rate affect resin reactivity that high HDT cause to produce reactive polyester.

The most use unsaturated acid is maleic acid. Generally, due to low melting point (m.p 60 °C) used as anhydride. Another acid is fumaric acid. It is trans isomer of maleic acid. Saturated acid, dibasic acid or anhydrides to “saturated” means that peroxide catalyst will not found to react free double bond. Ortha phtalic anhydride is used to prevent crystallization problems in production of saturated polyester. Ortha phtalic anhydride is compatible with styrene monomer. In addition, isophtalic acid is used widely to produce polyester. It provides water resistance to hardened resin. Also, it is used to produce chemical resistance polyester. There are some acids and glycols to manufacture polyester resins, which are mentioned below

Table II.1: Properties of different types of glycols

Glycols	Properties
Propylene Glycol	Chemical and water resistance
Ethylene Glycol	Low cost, providing rigidity(stiffness)
Dipropylen Glycol	Elasticity, Rigidity
Diethylene Glycol	Elasticity, Rigidity
Neopenthyl Glycol	UV resistance, water and chemical resistance

Table II.2 Properties of different types of acids

Acids	Properties
Phthalic Anhydride	Low cost, Compatible Styrene
Maleic Anhydride	Providing saturated
Adipic acid	Elasticity, Rigiditiy
Isophthalic asid	Heat, water and chemical resistance
Terephthalic acid	Heat, water and chemical resistance

Monomers is used for two purposes

i) Monomers provides to decrease viscosity of resin.

ii) Monomers provides to crosslink bonds between chains of polyester.

As an example, Figure II.7 depicts schematically the polyester monomers cross-linked by styrene monomers. As seen in the figure, styrene acts as a bridge between two polyester monomers, just reacting with the opened double carbon bonds of these corresponding monomers [21].

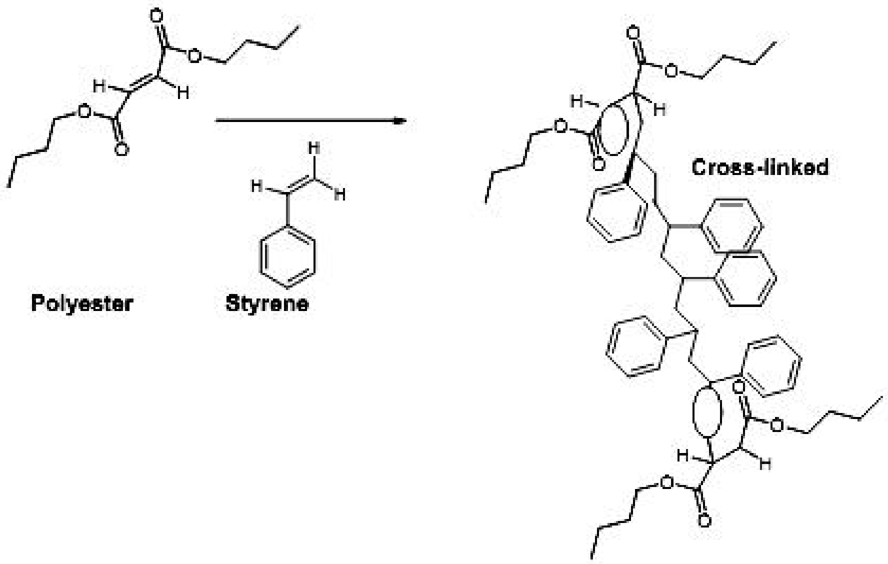


Figure II.7 Illustration of two polyester monomers cross linked via styrene

For this reason styrene is used widely as a monomers that has low cost, low viscosity, easy available. Another monomer is methyl methacrylate e and n-butyl methacrylate. They have ultraviolet stability.

Table II.3: Properties of different types of monomers

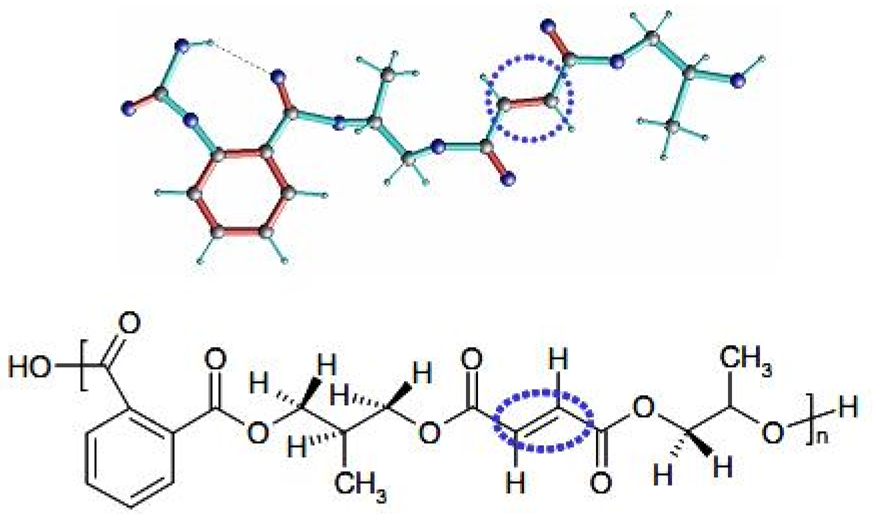
Monomers	**Properties**
Diallyl phthalate	Provides low shrink and elasticity to resin
Dibromo or dicloro styrene	Flame Retardant, expensive
Diallyl sulphonate	Flame Retardant
Triallyl cyanurate	Heat resistance

Inhibitory; when polyester polymer solved in monomer, it starts to gel without catalyst in room temperature. Inhibitory is added to prevent gelation. Inhibitors are generally reductant chemical materials. Free radicals of inhibitors absorption by giving hydrogen atom, thus they prevent to polymerization of resin.

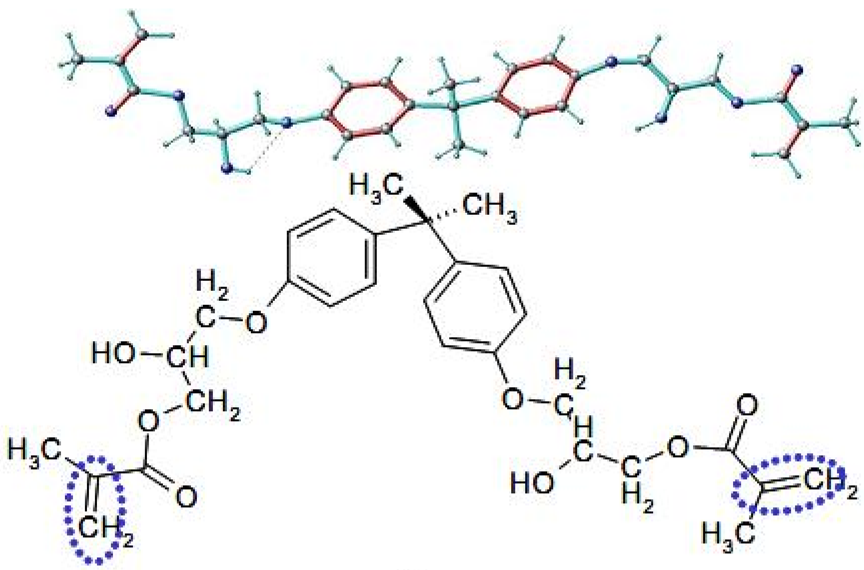
Polyesters are formulated desired specification and molding types. The advantages of polyester are mechanical, chemical and electrical properties, dimensional stability, low cost and ease of use [19].

Vinyl Ester

Vinyl ester (VE) monomers are addition products of various epoxide resins and ethylenically unsaturated mono carboxylic acids such as acrylic or methacrylic acids. On the other hand, the term unsaturated polyester (UP) resin is used to describe a class of thermosetting resins consisting of an unsaturated backbone dissolved in a reactive monomer (Kosar and Gomzi 2004) [20]. VE and UP resins are similar to each other in that they both contain styrene as a reactive diluents. Figure II.8 shows the chemical structure of polyester and vinyl ester resins. As seen in the figure, the UP monomers have usually more than two double bonds per molecule that are located inside the chain, while VE monomers have one double bond at either end of the molecule. In most of the commercial vinyl ester or polyester resins, the styrene concentration varies from 30 to 55 wt. %. However, the research done on UP cannot be directly used for VE resins due to one major difference between the two resins which arises from the number and the location of reactive groups (namely (C=C) bonds in VE and UP monomers (Dua, et al. 1999, Scott, et al. 2002) [22]. VE and UP monomers react via free radical chain growth copolymerization, forming cross-linked polymer networks by the aid of styrene in the system. Note that the term cross-links form between different polymer chains and assist in the formation of a network that tightens as long as the conversion increases.



a)



b)

Figure II.8 The chemical structure of a) thermosetting polyester and b) vinyl ester resins

Epoxy Resin

The first epoxy products were synthesized in 1891. In the 1930's, Pierre Castan (from Switzerland) and Sylvan Greenlee (in USA) patented their works at the same time, independently. The first commercial products marketed in the 1940's, and it was result of product was bisphenol A and epichlorhydrine reaction. One of the epoxy components is hardener, epoxy resins depend on the reactivity of hardeners [23]. Epoxy resins are cured with different curing agents like amines, amides, acids, acid anhydrides and amine adducts (figure2.9 -2.10) Cycloaliphatic curing agents better properties for applications of epoxy area such as weather ability, low blush and water spotting, and chemical resistance.

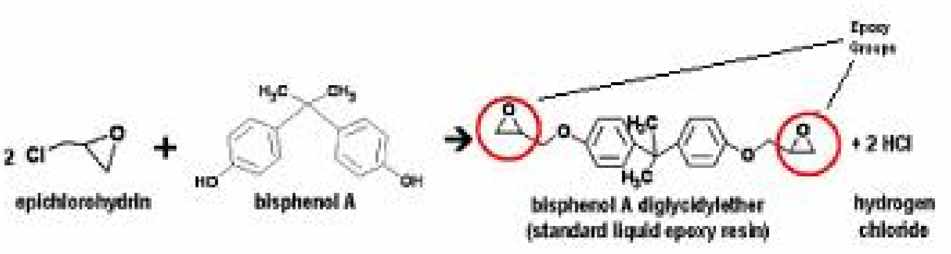


Figure II.9 The reaction mechanism of standard epoxy resin

By using suitable epoxy resin and hardener we can obtain materials which have significant mechanical, physical and chemical properties in order to use in a widely usage area. Because of resin chemistry and available applications, epoxy resins have been available for many major applications such as surface coating, tooling, civil engineering, molding compounds. Epoxy resins can manufactured from epiclorohydrine, ,bisphenol A, bisphenol F, tetrakis phenylolethane, resorcinol, metyhlolated phenol, brominated and fluorinated phenols [24]. Epoxy resins has widely used in industry for sixty years such as aircraft applications, the car industry, reinforcement to various concrete structures also thin film coating, electronic circuits Epoxy resin is mostly used as a matrix in material engineering due to their high stiffness, resistance of creep and chemical, also good adhesion.

The mechanical properties of epoxy resins can be modified because of its structure. Mechanical properties can be improved by crosslink density increasing due to molecular architecture and structure to get high endurance [25]. It can be obtained resins which have properties: toughness, chemical resistance, high strength and hardness, high adhesive strength, good heat resistance and high electrical insulation connected with chemical structure of curing agent and conditions of curing [26]. Because of available variation of epoxy components and reactions, many different resins can be obtained [27, 28]. Epoxy resin systems have wide usage industrial area in composite applications such as automotive and aerospace applications, for shipbuilding or electronic devices with surface coatings [29]. There are studies on polymer-based composites reinforced with filler to obtain high mechanical and high thermal polymer composites. There are some techniques such as effecting on processability, appearance, density, and ageing performance of the matrix to get these polymers [30]. Epoxy resins are mostly used with fiber to obtain reinforced composites. An epoxy resin with fiber reinforced has advantages such as good stiffness, specific strength, stability, chemical resistance, and show good adhesion to the fiber [31].

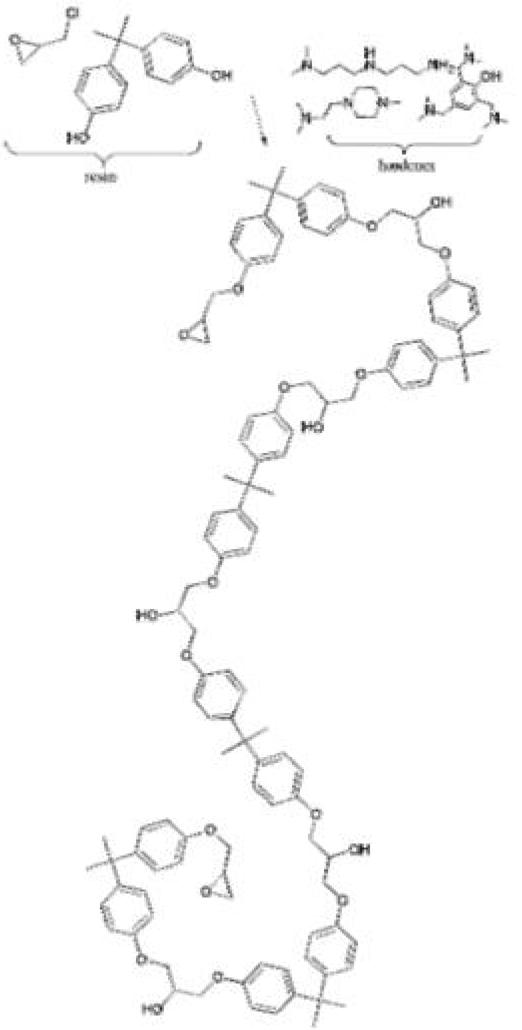


Figure II.10 Schematic diagram for epoxy synthesis from resin and hardener.

II.3.2 Reinforced Structure

The basic function of reinforced system is carrying distribution of load in composite structure and increasing rigidity and endurance of matrix. In addition, reinforced materials should establish a strong bond system with matrix system and should not cause to create unwanted products with the reaction matrix. The thermal expansions of reinforced should be the same with matrix due to suppress the effect of weakening each other when exposed to heat exchange [14]. The classification of composite groups is established according to the geometric shape of reinforced materials. With this approach, Composites are divided in two groups which are particle reinforced composites and fiber reinforced composites.

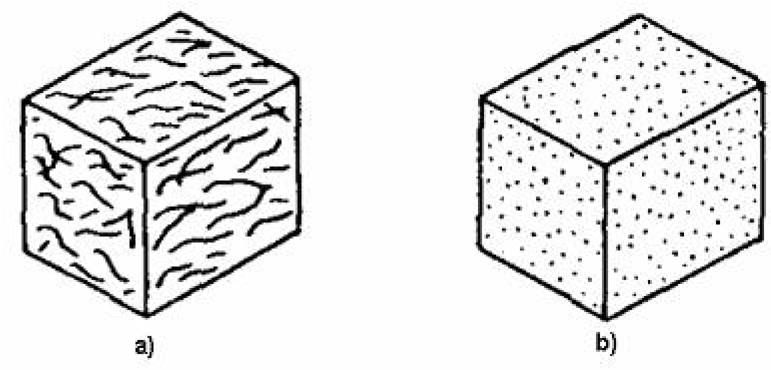


Figure II.11 particle and fiber reinforced composite structure

II.3.2.1 Fiber Reinforced Composites Materials

Fibers are used generally in thermoset and thermoplastic composite materials [32]. Mechanical strength of fiber is important for composite structure. Fiber structure of composite material is coated with elastic binder that is thermoset or thermoplastic tissue. All properties that will occur are determined by bonds that interconnection between matrix and fiber. Pressure is transferred to fiber by matrix when composite enforced. The majority of reinforced is hydrophilic, polar and water sensitive. In contrast, fibers must be hydrophobic. Hydrophobic properties are given by binder and sizing agents. In addition to chemical compatibility and reactivity of the binder with matrix resin as well as fiber sizing, physical properties of binder such as melt viscosity, wettability of the glass fabric and solubility in the applied matrix resin may significantly affect the properties of the final composite part Dissolution of the binder may directly cause an increase in the resin viscosity. This is an important parameter on the composite processing because permeability of the resin through the binder path depends upon the degree of dissolution of binder in the matrix resin [37]. Binders have both hydrophilic and hydrophobic pole. The role of poles provides to comport between fiber and matrix. Generally silan is used in glass fiber reinforcement as binder. Silan groups, that as a result of hydrolysis, binds with glass fiber over Si-O-Si bonds and the rest of the organic tail binds with matrix resin [32]. Dimension of fiber is important for mechanical strength of composites. Thin fiber increases mechanical properties of composite because of large surface area.

Glass fiber is used widely in plastic materials as reinforced because of low cost. Cotton, hemp, jute, aramid, kevlar, are used as reinforced materials besides glass fiber.

Endurance rate of glass fiber is mostly high. Elasticity modulus of glass fiber is higher than aluminum alloys; in contrast it is lower than graphite and aramid. Internal structure of glass fiber is not amorphous. Glass fiber reinforced plastics of rigidity/density rates are lower than metals'. Glass fiber has high chemical resistance but shrinkage strength decreases in humidity atmosphere [13].

The primary component of glass fiber is sand, but it also includes varying quantities of feldspar, sodium sulfate, anhydrous borax, boric acid, and many other materials [34]. In the glass melting furnace, the raw materials are heated to temperatures ranging from 1500 to 1700°C (2700 to 3100°F) and are transformed through a sequence of chemical reactions to molten glass. Although there are many furnace designs, furnaces are generally large, shallow, and well-insulated vessels that are heated from above. In operation, raw materials are introduced continuously on top of a bed of molten glass, where they slowly mix and dissolve. Mixing is effected by natural convection, gases rising from chemical reactions, and, in some operations, by air injection into the bottom of the bed [33]. Glass fibers are made from molten glass, and a chemical binder is simultaneously sprayed on the fibers as they are created. The binder is a thermosetting resin that holds the glass fibers together. Although the binder composition varies with product type, typically the binder consists of a solution of phenol-formaldehyde resin, water, urea, lignin, silane, and ammonia. Coloring agents may also be added to the binder. In the flame attenuation process, molten glass flows by gravity from a furnace through numerous small orifices to create threads that are then attenuated (stretched to the point of breaking) by high velocity, hot air, and/or a flame. After the glass fibers are created (by either process) and sprayed with the binder solution, they are collected by gravity on a conveyor belt in the form of a mat (figure 12) [33].

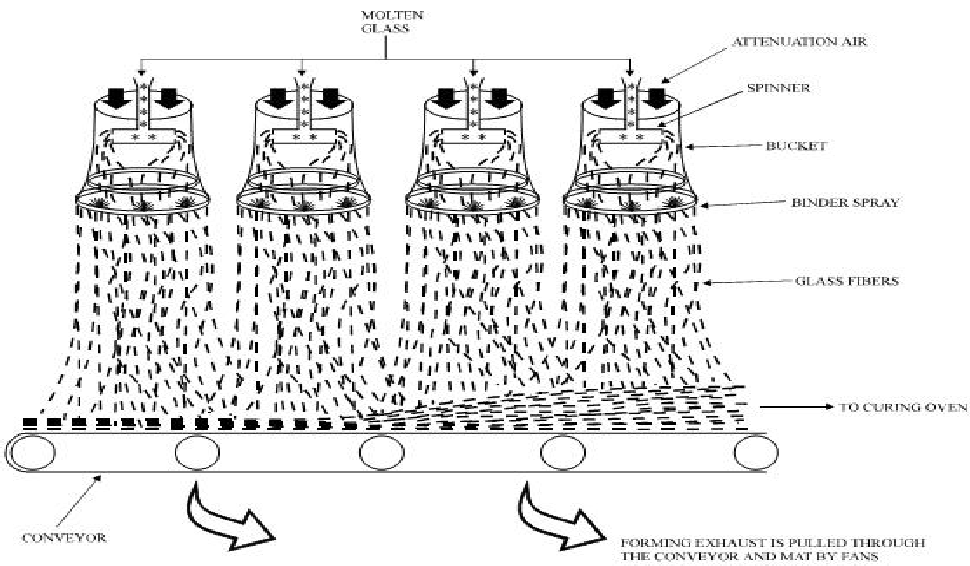


Figure II.12 Production of glass fiber

According to chemical composition of glass fiber is classified as A, E, C, D, R and S types.

A Glass **:** It is the old type of glass fiber. The form is window glass structure. It's alkali rate is higher.

E Glass **:** E comes from electricity. It is composed of calcium – aluminum and borosilicate mixing. Alkali rate is low and mechanical strength is high which are tensile, flexural and electrical. Its cost is lower than others.

C Glass **:** C comes from chemical. It resistants chemical substances. For this reason it is chosen for outside surface.

D Glass **:** Higher dielectric properties are determined D. It is used in electrical a sector that needs more electrical strength.

R-S Glass **:** There are variable chemical structures. They provide high tensile strength and modulus. They are used widely in air and defense industries. Higher mechanical strength increases by interlaminar force of fine fibers as a result better wetting.

Table II.4 Properties of glass fiber types (source Camelyaf San. A. Ş)

Properties	E Glass	S Glass	D Glass
Density (g/cm^3)	2.60	2.50	2.16
Elastic modulus E (GPa)	72	87	51.7
Tensile Strength σ (GPa)	3.45	4.54	2.41
Elongation Tensile (%)	4	2.9	-
Specific Modulus (MN/m)	27.7	34.8	23.9
Spesific Strength (MN/m/kg)	1.37	1.81	1.16
Coefficient thermal expansion ($\mu m/C°/10^{-5}$)	5	5.6	3.06

There are different forms of glass fiber used in plastic industries. The types of glass fiber are continuous fiber, mats, textiles, different length chopped and fabric.

Continuous Fiber (Roving) : Roving is compose of fiber that coated binder. The glass fiber bunches is formed cylindrical packet. They are served by stated text count such as 2400 text or 4800 text. Roving has high mechanic resistance on tensile. In this way, roving is used pultrusion and other necessary high mechanical properties methods. Roving is used also chopped by a blade in sheet molding compound process [32] (Figure II.13a).

Chopped Fiber: There are different length of chopped fibers such as 3, 6, 12 mm length. They are used in bulk molding compound (Figure II.13b).

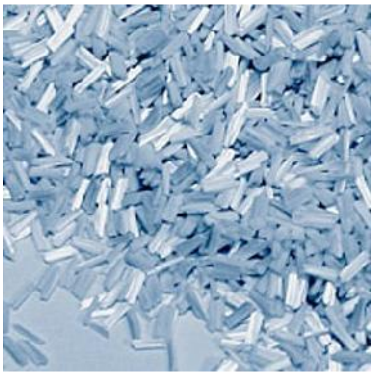
Woven Fiber: Woven fiber is produced different weight and shape. Its weight is adjusted according to needs. The basic factor of woven is weight and thickness of fiber. Thickness and weight may cause delimination. For this reason woven fiber is used with chopped fiber to prevent delimination. Composites are manufactured with high mechanical properties as prevented delimination.

Woven Roving : Rovings are woven together to form a right angle. Mechanical strength increases both one and cross directions (Figure II.13c).

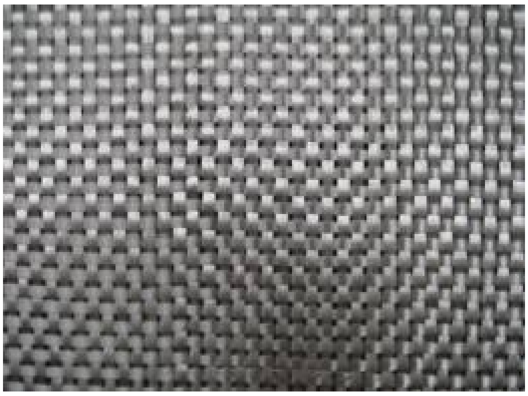
Glass Fiber Mat : Mat is composed with coated binder chopped glass fiber. The length of the chopped fiber changes between 3, 2 mm and 50 mm. Mats are produced from 300g/m^2 to 700g/m^2 weights. Mat's fiber could be connected with resin and distributed in mold. In addition mat glass fiber provides smooth surface and high mechanical properties between layers (Figure II.13d) [32].

Table II.5 Properties Types of Glass fiber

Properties	Unit	Textile	Mat	Roving
Ratio of GF	%	55	30	70
Specific Gravity	g/cc	1.7	1.4	1.9
Tensile Strength	MPa	300	100	800
Load Strength	MPa	250	150	350
Flexural Strength	MPa	400	150	1000
Flexural Modulus	GPa	15	7	40
Impact Strength	Kj/m^2	150	75	250
Coefficient Thermal Expansion	10 °C	12	30	10

a) Roving b) Chopped Glass Fiber

c) Woven Fabric d) Glass Fiber Mat

Figure II.13 Types of Glass fiber

II.3.2.2 Particle Reinforced Composite Materials

Particulate composite, reinforced with a component in all directions at approximately the same size as the particles are within a matrix material. Shapes of particles spherical, cubic, or can be of different geometries.

In this material, load is moved together by the reinforcement and the matrix, and feature is usually isotopes. Aluminum alloys reinforced with silicon carbide particles, rigid threaded inserts and concrete composite materials are given as an example [34].

II.3.2.3 Laminated Composites

The Laminated composites are consist of layer with different characteristics by put in a row [34]. The layers are placed to create laminated composites that shown Figure II.14.

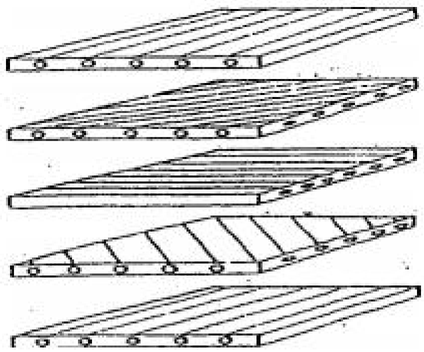


Figure II.14 The Demonstration of Layered Positions

The fibers in a composite are strong and stiff and support most of the applied loads. The matrix contributes mainly to the service temperature, toughness, and environmental resistance of the composite. As a result unidirectional composites (UD) have predominant mechanical properties in one direction and are said to be anisotropic. Isotropic materials (most metals) have equal properties in all directions.

Components made from fiber -reinforced composites can be designed so that the fiber orientation produces optimum mechanical properties, but they can only approach the true isotropic nature of metals [35].

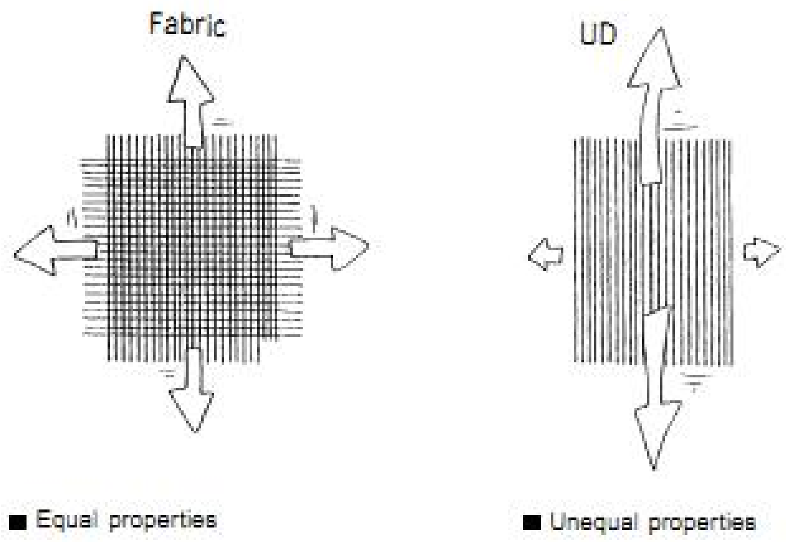


Figure II.15 The Demonstration of Properties of Unidirectional and Fabrics

The fiber directions can be arranged to meet specific mechanical performance requirements of the composite by varying the orientation.

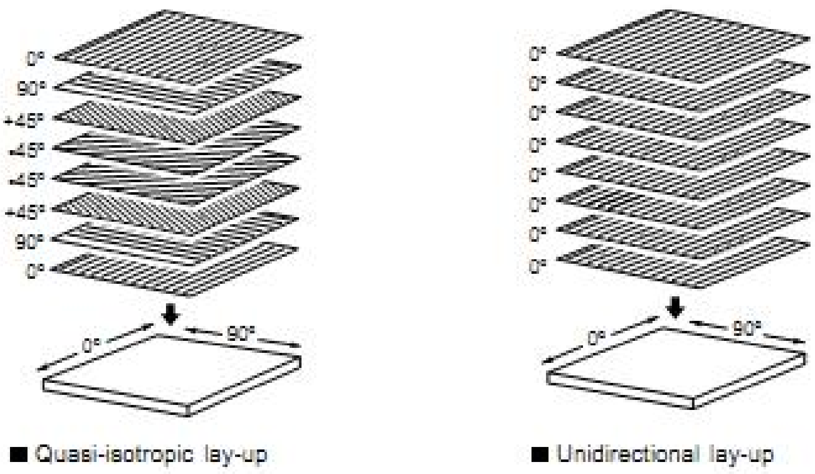


Figure II.16 The Demonstration of orientation

Impact resistance of composite structure is determined elasticity modulus, braking yield of fiber and density of composites surface [36]. Laminated composite method is used in many researching. Cimproeru S.J, Gellert E.P and Woodward R.L works on ballistic penetration of fabrics and composites. Their aim is based on protection of personnel against ballistic threats by using impregnated glass fiber and synthetic textiles. They examined fiber response, mechanism of deformation and failure as well as energy absorption and dynamic loading. They used woven roving E-Glass GRP of 11 plies (4.5 mm,27 % resin), 22 plies (9 mm, 28}29 wt % resin), 33 plies (14 mm, 27 wt % resin) and 44 plies (20 mm, 29}30 wt % resin) of a nominal 608 g/m^2 woven cloth and DerakaneTM 411-45 vinyl ester resin [37].

Tanoğlu M and Seyhan T. investigated the effects of a preforming binder on the mechanical properties and ballistic performance of E-glass-fiber/polyester composite systems. They evaluated composite laminates with and without binder were fabricated using vacuum assisted resin transfers molding (VARTM) technique and the effects of the binder on the composite mechanical properties. Ballistic test was performed on E-glass/polyester composite panels using 1.1 g fragment-simulating projectiles and it was found that the binder amount has some considerable effect on the damage extension of the impacted composites. Experimental result showed that the performing binder has significant potential to tailor composite properties [38].

II.4 Auxiliary Materials for Composite

Polymers are reinforced with fibrous rigid materials to improve their physical and mechanical properties, and combined with fillers to further improve properties but more importantly to reduce the final cost. Composites is composed basically of four principal ingredients; thermosetting resins, fibers, fillers and additives. The thermosetting resin could be unsaturated polyester, an epoxy, a phenolic or another compound. There are even a greater variety of additives, which are used to improve material properties and processing characteristics. The list includes inhibitors, initiator, low–profile additives, thickening agents, internal mold releases, viscosity reducers and wetting agents. In comparison, the lists are shorter for fillers and fibers. Among the more commonly used fillers are calcium carbonate, alumina trihydrate and hollow glass microsphere, whereas glass, carbon, and kevlar fibers are among the possible reinforcements for composites [39].

II.4.1 Initiators and Inhibitors

Organic peroxides play a key role in this copolymerization by providing a convenient of free radicals to initiate the copolymerization reaction.

Organic peroxides are derivates of hydrogen peroxide, HOOH, wherein one or both hydrogen are replaced by an organic group, for example, ROOH or ROOR'. Free radicals are produced by the thermal decomposition of the peroxide.

Inhibitors are added to polyester resins primarily to prevent measurable levels of unwanted copolymerization or cross linking.

II.4.1.1 Organic Peroxides

Organic peroxides (ROOR') decompose thermally to produce free radicals by initial cleavage of the oxygen – oxygen bond:

$$R\text{-}O\text{-}O\text{-}R' \rightarrow RO\cdot + \cdot OR' + \Delta$$

When formed in a resin these free radicals are available to start or initiate the cross linking reaction. Thus, organic peroxides are referred to as "initiators".

Generally, the effectiveness of an organic peroxide initiator depends on its thermal decomposition rate at a given temperature and on the ability of the free radicals formed to carry out the desired reaction.

The four major classes or types of organic peroxides used to cure composites are listed below.

a) Diacyl Peroxide
b) t – Alkyl Peroxyester
c) Di (t-alkyl) peroxyketal

d) Di-t-alkyl peroxide

Peroxyesters and peroxyketals are two most common classes of peroxides used in the curing of composites; diacyl and dialkyl peroxides are used to a limited degree. Peroxyesters can also be readily accelerated by transition metals such as cobalt and vanadium to decrease cure time at any given temperature. In comparison, peroxyketals offer fast cure reactivity combined with long pot-lives because they are more resistant to induced decomposition caused by formulation components such as pigments and fillers.

Application temperature is another important factor in choosing the right initiator. For instance, dialkyl peroxides, because of their high thermal ad chemical stability, provide long shelf life in composites formulations; however, this same thermal stability requires higher molding temperatures to achieve desirably fast cure times. As a result this type of peroxide has limited usage [39].

II.4.1.2 Inhibitors

Inhibitors function by reacting with growing polymer chain radicals to produce a radical of low reactivity that shows a reduced tendency for propagation. Inhibitors act to retard polymerization of the resin. Polymerization inhibitors are used not only to prolong the shelf- life of composite materials but also modify cure rate and magnitude of exotherms to prevent cracking of thick molded sections. Inhibitors are also used to improve resin stability by minimizing undesirable changes in gel time on long- term resin storage.

Two general classes of inhibitors are phenolic derivatives and quaternary ammonium salts. The use of hydroquinone, quinone, and their derivatives is very common in polyester resin manufacture.

II.4.2 Low profile Additives: Shrinkage Control

There were some applications for compression molding of sheet molding compound and other resin compounds, growth into many high volume applications was excluded because of a number of a problems.

a) Poor surface appearance, including fiber pattern which required costly sanding operations for painted, appearance applications and prohibited use in high appearance internally pigmented applications.
b) Warpage of molded parts and an inability to mold close tolerances
c) Internal cracks and voids, particularly in thick sections
d) A notable depression on the surface opposite reinforced ribs and bosses

The cause of these problems was believed to be the high – polymerization shrinkage from the copolymerization of the thermoset resins with the cross linking monomer. The resin volume shrinkage causes the compound to pull away from the surface of the mold and shrink away from the fibrous reinforcement. This reduces the accuracy of mold and shrinks away from the fibrous reinforcement. The stresses created by nonuniform shrinkage cause warpage and internal cracks and prohibit molding close tolerances.

Many approaches were tried to solve these problems, including major changes in resin and co-monomer structures, use of large amounts of filler, and even partial polymerization of the resin before molding, none were successful. The ultimate solution to the problem has been te addition of certain thermoplastics to the formulation of the composite. The degree of improvement in shrinkage control is depended on the structure of the thermoplastic, its molecular weight, the amounts used, and the structure of thermoset resin employed; however, with proper attention to these factors a " zero shrinkage" composite can be assembled to yield moldings with excellent surface smoothness, no part warpage, and precise dimensional stability.

A number of thermoplastics have been found to give varying levels of shrinkage control. Examples are polyvinyl acetates, polymethyl methacrylates and copolymers with other acrylicates, vinyl chloride – vinyl acetate copolymers, polyurethanes, styrene- butadiene copolymers and other elastomers, polystyrene and some copolymers, polycaprolactones, cellulose acetate butyrate, and a variety of saturated polyesters and blends of saturated polyesters with poly (vinyl chloride). These polymers, when blended in appropriate ratios with thermoset resins and comonomers, result in shrinkage control under both standard compression and injection molding conditions [39].

II.4.3 Fillers

Filler are widely used in polymer compounds to improve physical properties and reduce costs. They are typically divided into functional and nonfunctional categories. Alumina tryhidrate and hollow glass bubbles are examples of functional fillers used in auxiliary materials. They are used for flame retardancy and weight reduction, respectively.

Nonfunctional fillers are used primarily for cost reduction purposes. They are produced from minerals that can be mined and processed inexpensively, for example, talc, lime stone, sand or from organic by products, for example, walnut shells, wood flour.

Basic Requirements of an Ideal Filler are listed below [39];

a) Produces pastes of moderate thixotrpoy at high loadings
b) Low resin demand
c) Low moisture contents, 0.1 % max.
d) High Strength
e) Consistency
f) Low cost
g) Nonabrasive,Low Specific
h) Low specific gravity
i) Absence of contaminants/surface groups that interfere with the thickening or maturation reactions
j) High brightness

II.4.3.1 Alumina Tryhidrate Fillers

Alumina trihydrate (ATH) property is its endothermic decomposition into water and alumina over the temperature range 220 to 320 °C.

$2Al(OH)_3 \rightarrow Al_2O_3 + 3\ H_2O$

When ATH- filled laminates are exposed to fire, the filler absorbs heat energy required to sustain combustion and releases water vapor (34.6% of its weight), which suppresses smoke formation and dilutes the combustion gases.

ATH fillers are sometimes used in conjunction with halogen and antimony flame retardants; however, recent fire safety concerns have placed more emphasis on the reduction of toxic gas emissions. ATH fillers are also used in composites laminates for their ability to improve arc and track resistance. The degradation of polymers by electrical arcing creates conductive carbon pathways, which results in a significant loss in insulating properties. The heat adsorption and water release of ATH fillers inhibit this polymer degradation [32].

II.4.3.2 Barite

Fine ground barite (barium sulfate, specific gravity 4.4 g/cm^3) fillers are used in compounds requiring X-ray opacity. They are also being considered for sound- deadening applications, for example, passenger van engine cowles. Barite fillers have excellent acid resistance and lower abrasivity compared with nepheline syenite or silica fillers. Their high specific gravity is a drawback in many applications [32].

II.4.3.3 Kaolin Clays

Kaolin clay is used occasionally in products requiring hot oil and corrosion resistance. The coarse particle size products, specific gravity 2.58, median particle size 4 to 5 µm, and moisture content are preferred to minimize resin demand and moisture adsorption [32].

II.4.3.4 Ground Silicas

Silica fillers are also recommended for compound applications requiring stain and corrosion resistance. They have low resin demand and low moisture contents. Their high moh hardness (6 to 7) prevents any extensive use in compounds.

III.4.3.5 Limestone (calcium carbonate)

Limestone deposits of economic significance are formed from the accumulation of the remains of marine organisms. Fillers produced from chalk, reef, sedimentary limestone and marble by wet – ground marble fillers initially gained a dominant position in composite compounds [39]. Calcium carbonate is used widely in plastic industries. The properties of calcium carbonate are mentioned below,

a) Calcium carbonate must be pure in matrix systems not to create problems via metal ions.
b) It should not create agglomerates.
c) It should not abrasive metals
d) It should increase stiffness and e –modulus
e) Low cost [32]

II.4.3.6 Talc

Talc is found in nature as four shapes which are fibrous, flat, acicular and modular. Flat shape is used as filler. Talks provide to increase stiffness, flexural, tensile strength and surface improvement. In contrast, talk decreases impact strength, melt flow rate. In addition, talc has not low cost [32].

II.4.3.7 Kaolin

Kaolin is occurred from feldspar and decomposition of granite. Kaolin is hydrolyzed alumina silica. Their structure is hexagonal shape. Kaolin colors are pure white. Kaolin is used for resistance for chemicals, water and outside effects. In addition electrical properties of kaolin is mostly high [32].

II.5 Manufacturing Composite Techniques

In function of composite constructions, those can be divided in two categories

- Laminates, which have layers bonded together,
- Sandwiches, which are multiple-layer structural materials containing a low-density core between thin faces (skins) of composite materials. As an observation, can be mention that in some application of advanced composite materials, the individual layer may themselves be composites, usually of fiber-matrix type. Composites fabrication have many processes, some of the most important processes are:

a) Hand and automated tape lay-up

b) Resin injection,

c) Compression molding,

d) Pultrusion,

e) Filament winding.

Other classification of composites process can be after the process volume, which due to of two categories: high and low volume. Low-volume processes are manual and low-pressure spray lay-up in low-cost molds with a high working cost. High-volume processes, such as lamination, filament-winding, pultrusion and resin transfer molding, have an initial high cost for tooling and installation, which are compensated by low-intensity of working. In addition, lamination processes can be found in both of them, lamination as a hand lay-up process, or as the automated using sheet-molding compounds.

Lamination, filament winding, pultrusion and resin transfer molding are relevance in production of continuous fiber composites with closely controlled properties, being used for obtained of comparative flat parts. A potential and high-speed process in fabrication of tubs and other cylindrical parts represents the filament-winding process, in which time the pultrusion process is applied for fabrication of parts with constant cross-sectional shapes, and resin transfer molding shares some similarities with injection molding [40].

II.5.1 Hand and Automated Tape Lay-Up

Hand lay-up is a simple method for composite production. A mold must be used for hand lay-up parts unless the composite is to be joined directly to another structure. The mold can be as simple as a flat sheet or have infinite curves and edges. For some shapes, molds must be joined in sections so they can be taken apart for part removal after curing. Before lay-up, the mold is prepared with a release agent to insure that the part will not adhere to the mold. Reinforcement fibers can be cut and laid in the mold. It is up to the designer to organize the type, amount and direction of the fibers being used. Resin must then be catalyzed and added to the fibers. A brush, roller or squeegee can be used to impregnate the fibers with the resin. The lay-up technician is responsible for controlling the amount of resin and the quality of saturation [41].

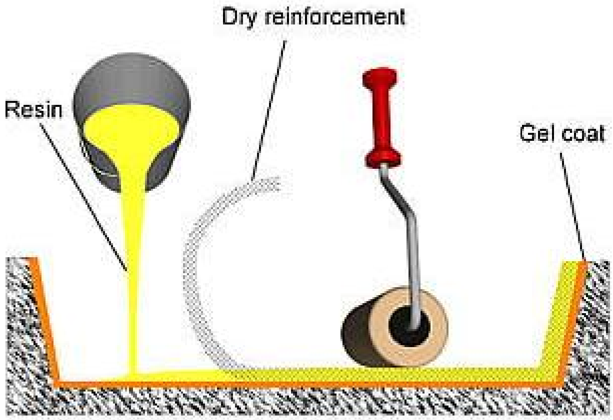


Figure II.17 The Basic Process of Hand Lay-Up

P.Feraboli and K.T. Kedward studied on a new composite structure impact performance. They obtained their laminates via using hand lay-up methods. After that the laminates were press molded at 149 °C for 30 min. at 3 bars pressure. The stacking sequence was quasi-isotropic of the form [0/90/±45]. Their reference laminate was a 32 ply with nominal thickness of 3.68 mm. The result was obtained laminate thickness had a significant effect on the impact as impactor size and modulus [42].

E.P Gellert, S.J. Cimpoeru and R.L. Woodward studied on the effect of target thickness on the ballistic perforation of glass fiber reinforced plastic composites. Their studies were based on ballistic penetration of fabrics and composites had examined fiber response, mechanisms of deformation and failure as well as energy absorption and dynamic loading. They were obtained their laminate panels via using hand lay- up processes. The laminate panels were cured with methyl ethyl ketone peroxide catalyst and 0.3 % cobalt octoate co-catalyst, autoclave cured 30 °C and 100 kPa for 1h and post cured for 2 h at 90 °C. The result was obtained the indentation phase is a more significant absorber of energy and should be maximized in any bonded composite amour design, indicating that thicker targets are more efficient ballistically, especially against blunt projectiles. Energy absorption in thin GRP targets is largely independent of projectile nose geometry and that thin GRP and Kevlar targets respond similarly on a thickness basis against fragment simulator projectiles [37].

N.Tarım, F. Fındık and H. Uzun studied on ballistic impact performance on composite structures. They had obtained glass fiber layer via using hand lay up processes that the layers were 6, 12, 18, 22, 28 and 36 plies. Their results were obtained that the thinner composite plates have higher elasticity than the thicker ones in the ballistic testing. The bending and tensile strength were increased with the increments of composite layers. Ultrasonic inspection of composite layers after the ballistic testing showed that complete holes occurred in the 18 and 22 layers of composite. However no holes were observed in the 28 and 36 layers of composite. The velocity of the bullet was decreased with the increment of layer numbers. In contrast, output was obtained as the opposite behavior of speed. The depths of trace of the bullets are decreased with the increment of layer numbers. Also, there was a direct proportionality between speed and the trace depth for all layer numbers. In addition, the penetration depth was increased with the increment of bullet speed [43].

Vacuum bagging follows similar steps to the hand lay-up process. When the resin is adequately impregnated into the fibers with excess, the part is sealed with vacuum bagging materials. A layer of peel ply is laid down on the part because the resin will not stick to peel ply. Then a layer of breather cloth is laid down to soak up excess resin and insure an adequate path for the vacuum pressure. Then a layer of plastic sheeting is laid down and sealed around the part to isolate the part from the atmosphere. A hose connected to a vacuum is attached to the sealed part. A vacuum is then applied to the enclosed part. The part will be compacted by the vacuum and the breather cloth will collect the excess resin [41].

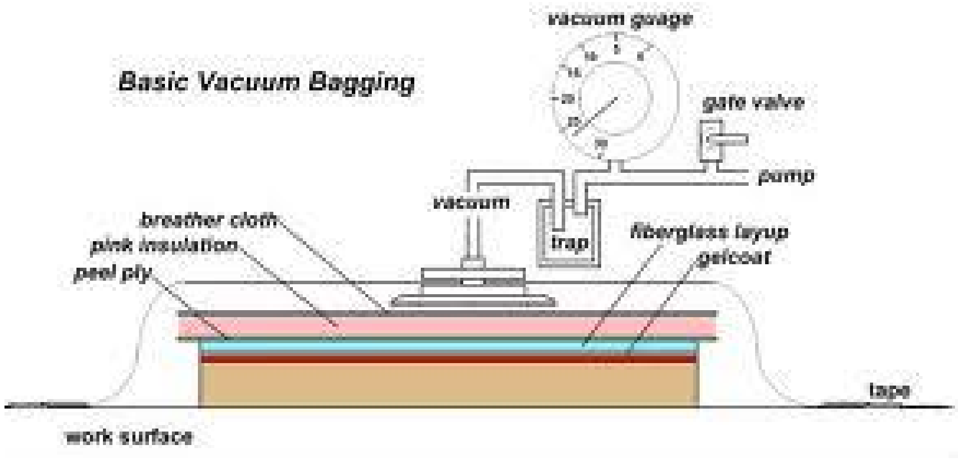


Figure II.18 The Basic Process of Vacuum Bagging

II.5.2 Resin Transfer Molding

Vacuum resin transfer molding is similar to vacuum bagging. Vacuum resin transfer molding follows the first steps of hand lay-up. The mold is prepared with a release agent, the fibers are cut and placed into the mold, and then new steps are taken. The next steps are as follows: a layer of peel ply is laid down on the fibers, a layer of mesh netting is laid on the part, special air tubes are fixed at desired entrance and exit points, vacuum tubes are connected to the air tubes, the part is sealed with plastic sheeting and a vacuum is applied. The part and mold are then heated with vacuum still applied to allow resin transfer into the part occur properly. Catalyzed resin is then degassed to remove volatiles. When the part and mold have reached the desired temperature, one vacuum tube will remain connected to the vacuum and the other will be used to draw the degassed resin. The part will be left under vacuum and cured under additional heat for a predetermined amount of time [41].

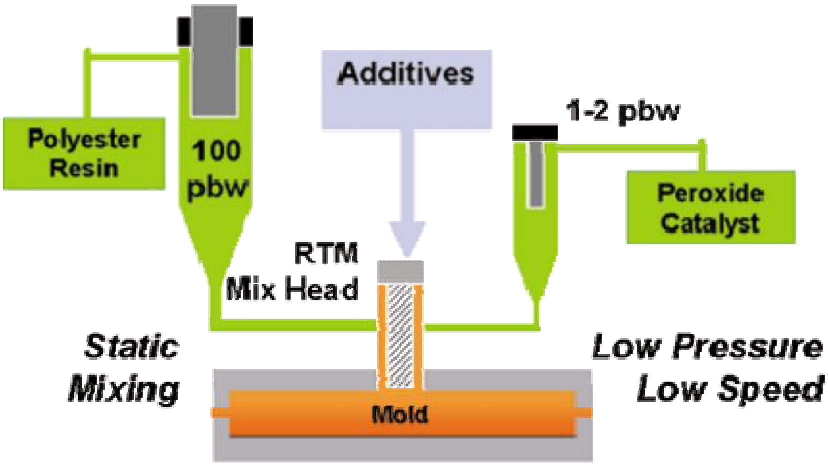


Figure II.19 The Basic of Resin Transfer Molding

M.Tanoğlu and A.T. Seyhan studied on a investigating the effects of a polyester preforming binder on the mechanical and ballistic performance of E-glass fiber reinforced polyester composites. They obtained composite laminates via using vacuum resin transfer molding technique. In this technique, performs were placed on a flat tool that was coated with release agent to ease the peeling of the parts. Preforms were infused with the reacting resin under a vacuum pressure. After completion of the resin infusion and curing, the parts were demolded and transferred into an oven for post- curing at 110 °C for 2h. The results of the ballistic test showed that failure damage due to the ballistic impact was also considerably affected by the presence of the binder.

The extend of the delamination type damage was observed to change due to the preforming binder. The results indicate the potential of the preforming binder to modify the properties at interlaminar region and to tailor the mechanical and ballistic performance of the polymeric composites [38].

II.5.3 Compression Molding

Compression molding is the most common method of molding thermosetting materials such as SMC (sheet molding compound) and BMC (bulk molding compound). This molding technique involves compressing materials containing a temperature-activated catalyst in a heated matched metal die using a vertical press.

The molding process begins with the delivery of high viscosity uncured composite material to the mold. Mold temperatures typically are in the range of 350° - 400° F. As the mold closes, composite viscosity is reduced under the heat and pressure approximating 1000 psi. The resin and the isotropically distributed reinforcements flow to fill the mold cavity. While the mold remains closed, the thermoset material undergoes a chemical change (cure) that permanently hardens it into the shape of the mold cavity. Mold closure times vary from 30 seconds up to several minutes depending on part design and material formulation. When the mold opens, parts are ready for finishing operations such as deflashing, painting, bonding, and installation of inserts for fasteners. By varying the formulation of the thermoset material and the reinforcements, parts can be molded to meet applications ranging from automotive class ‘A’ exterior body panels to structural members such as automobile bumper beams. [44]

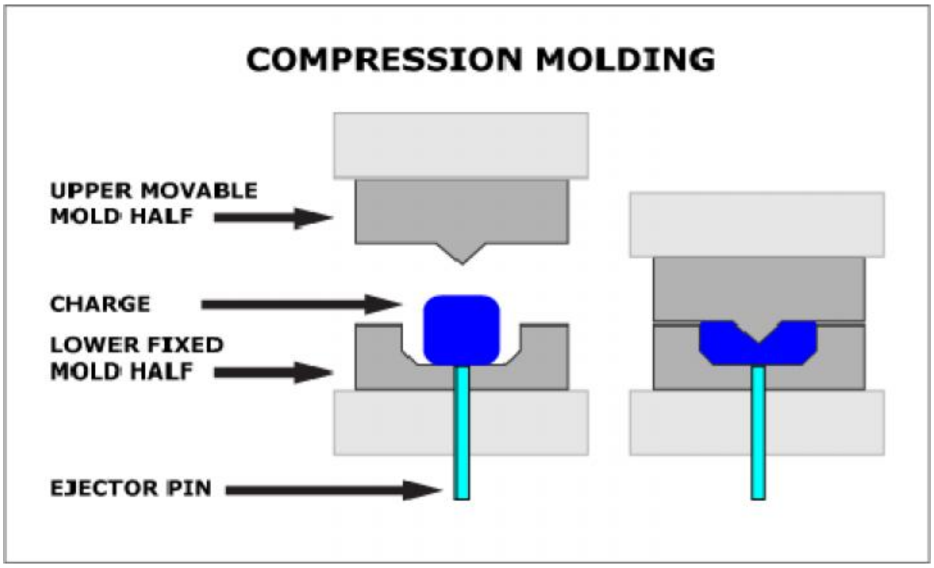


Figure II.20 The Basic process of Compression Molding

II.5.3.1 Sheet Molding Compound Processes

Sheet molding compound (SMC) technology comprises two distinct manufacturing steps; Compounding and molding. In the compounding operation all ingredients, except the fiber, are mixed together to form paste. The fibers are then wetted with this paste to form the final compound. The specific format of the compounding operation naturally depends on the types of ingredients, which vary extensively. For instance, the thermosetting resin could be an unsaturated polyester, an epoxy, a vinyl ester, a phenolic, or another compound. There are even a greater variety of additives, which are used to improve material properties and processing characteristic. The list includes inhibitors, initiators, low profile additives, thickening agents, internal mold releases, viscosity reducer and wetting agents. In comparison, the lists are shorter for filler and fibers. Among the more commonly used fillers are calcium carbonate, alumina trihydrate and hallow glass microspheres, wheras glass, carbon, and kevlar fibers are among the possible reinforcements for SMC. Today; the majority of SMC parts are made using chopped glass fiber for reinforcement, calcium carbonate as a filler, an unsaturated polyester combined with the styrene as thermosetting resin, a low profile additive such as polyvinyl acetate, magnesium oxide, or hydroxide as a thicker, zinc stearate as an internal mold release, p- benzoquinone as an inhibitor and peroxide initiator such as t-butyl peroxybenzoate.

In the compounding process for this type of formulation in the ingredients are mixed in same batch in order to obtained SMC paste [39].

In processing of SMC machine; paste reservoir dispenses a measured amount of specified resin paste onto a plastic carrier film. This carrier film passes underneath a chopper which cuts the glass rovings onto the surface. Once these have drifted through the depth of resin paste, another sheet is added on top which sandwiches the glass. The sheets are compacted and then enter onto a take-up roll, which is used to store the product whilst it matures. The carrier film is then later removed and the material is cut into charges. Depending on what shape is required determines the shape of the charge and steel die which it is then added to. Heat and pressure act on the charge and once fully cured, this is then removed from the mould as the finished product [45].

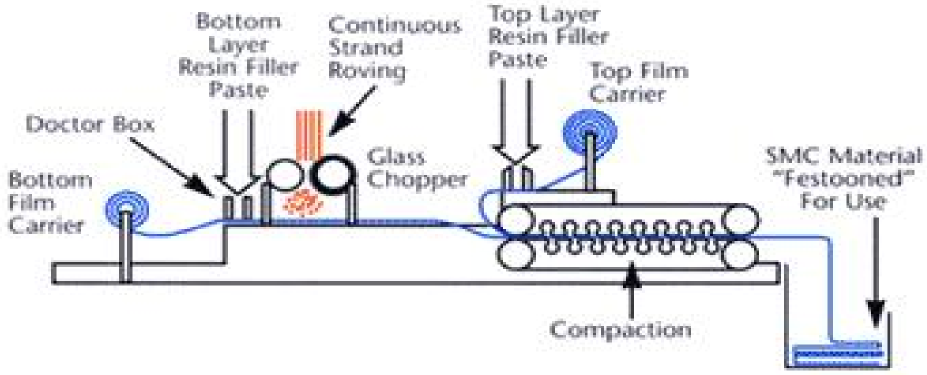


Figure II.21 The Sheet Molding Compound Machine

II.5.3.2 Bulk Molding Compound (BMC)

Like SMC, BMC is a fiber reinforced composite material which primarily consists of an amalgam of thermosetting resin, chopped glass fiber reinforcement and filler in the form of a bulk material. Additional ingredients such as low profile additives, cure initiators, thickeners and mould release agent are added to enhance processing performance. BMC is less loaded with glass fibers than SMC and fiber length is shorter at 6 to 12mm. Filler loadings are higher than for SMC. There are several techniques for the batch production of BMC. The most common mixing process involves a Z-blade mixers which amalgamates the resin paste, fillers, additives and reinforcements into a mass material with a dough-like consistency. The bulk product is packed in plastic bags impermeable to styrene diffusion and supplied in bins. Like with SMC, it can be supplied in pre-weighed charges according to customer needs.

BMC can be formulated to provide, more or less, similar properties to SMC. Due to the shorter fiber length, it is well suited to injection molding where it flows freely into the smallest cavities, making it suitable for the most intricate parts. The higher inorganic filler load guarantees very high temperature resistance and an extremely good surface appearance, which is why BMC is commonly used for headlamp reflectors and appliances requiring good cosmetic and high heat performance such as steam iron housings and coffee machines. BMC combines excellent electrical and mechanical properties with good moldability and high dimensional accuracy in the finished part. An advantage over traditional thermosets commonly used for electrical and heat sensitive parts is that BMC can be pigmented to a wide range of colors. See Applications section for more details [46].

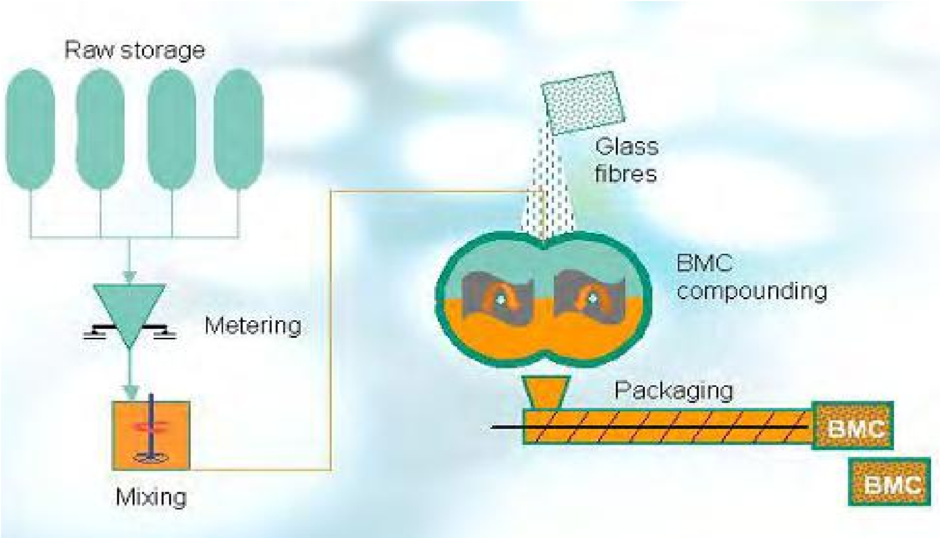


Figure II.22 The BMC manufacturing Processes

II.5.4 Pultrision

The process is normally continuous and highly automated. Reinforcement materials, such as roving, mat or fabrics, positioned in a specific location using preforming shapers or guides to form the profile. The reinforcements are drawn through a resin bath or wet-out where the material is thoroughly coated or impregnated with a liquid thermosetting resin. The resin-saturated reinforcements enter a heated metal pultrusion die. The dimensions and shape of the die will define the finished part being fabricated. Inside the metal die, heat is transferred initiated by precise temperature control to the reinforcements and liquid resin. The heat energy activates the curing or polymerization of the thermoset resin changing it from a liquid to a solid. The solid laminate emerges from the pultrusion die to the exact shape of the die cavity. The laminate solidifies when cooled and it is continuously pulled through the pultrusion machine and cut to the desired length. The process is driven by a system of caterpillar or tandem pullers located between the die exit and the cut-off mechanism [44, 47].

Pultrusion Advantages:

1. Increased Strength (fiber processed under tension)
2. High Fiber Content
3. Highly Automated
4. Consistent Quality
5. High Production
6. Low Labor Required
7. Low Cost

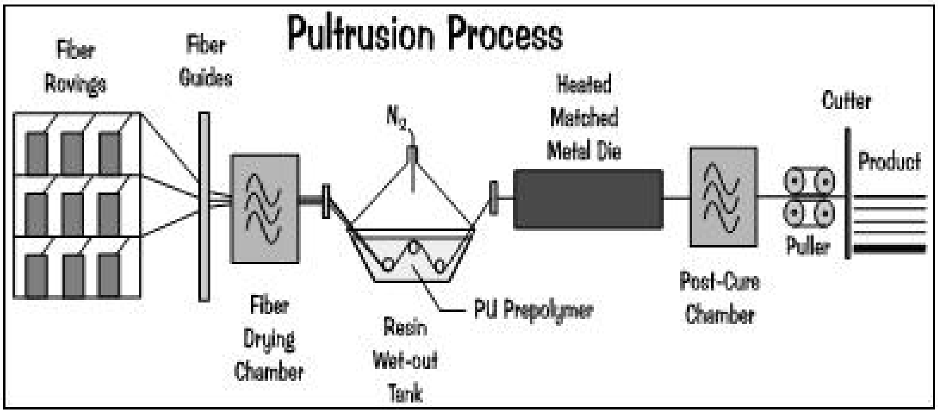


Figure II.23 The Basic Processes of Pultrision

II.5.5 Filament Winding

Filament winding is a fabrication technique for creating structures using fiber-reinforced plastics (FRP, or composite materials). The process involves winding filaments under tension over a male mould or mandrel. In the most simple form of winding, the mandrel rotates on a spindle around a horizontal axis, while a carriage moves backwards and forwards horizontally, laying down fibers in the desired pattern. The most common filaments are carbon fiber, glass fiber and aramid fiber (eg 'Kevlar'). These fibers are coated (impregnated) with a liquid synthetic resin just before they are wound in the process known in the composites industry as 'wet-winding'. However, it is also possible to filament wind fibers which have been 'pre-impregnated' with a solid, but flexible resin that hardens only when exposed to heat [48].

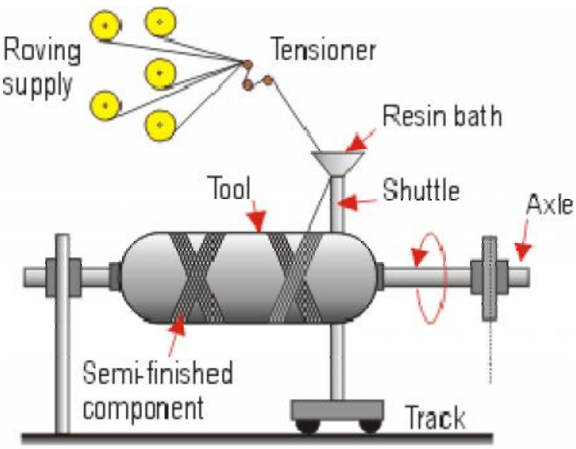


Figure II.24 The basic process of Filament Winding

Once the mandrel is completely covered to the desired thickness, the mandrel might be placed in an oven to solidify (cure) the resin. However, with many resin systems it is also possible to conduct room-temperature cures. Once the resin has cured, the mandrel is often removed, leaving a hollow final product. However, some products such as pressure vessels permanently leave the mandrel inside the composite reinforcement, and it becomes an integral part of the final product. In the case of pressure vessels, what was used as a mandrel during the winding process, acts as a ’liner’ (to maintain a seal and prevent the leaking of a pressurized gas or liquid inside) during operation [48].

Filament winding is well suited to automation and is a relatively inexpensive method of automated production and prototyping. Using computer control, the orientation of the filaments can be carefully controlled so that the fibers of one layer are oriented differently from the previous layer. The angle of the fiber orientation determines the structural properties of the final product. A high angle "hoop" or “circumferential” layer will improve crush strength, while a lower angle pattern (known as a closed or helical) will provide greater strength in the longitudinal direction. There are a wide range of products currently being produced using this technology, for example: pressure vessels, pipes, water and other tanks, golf club shafts, oars, bicycle forks and tubes, power and transmission poles, missile casings, aircraft fuselages, lamp posts, yacht masts and booms [48].

Table II.6 Comparison of Production Processes [48]

	Hand Lay-up	Filament Winding	Pultrusion
Investment for single part	Low	High	Very High
Investment for multiple parts	Low	Medium	Medium
Investment for mass production	Medium	Low	Low
Labor cost	High	Medium	Low
Fiber resin ratio(no vacuum)	Poor	Good	Excellent
Fiber resin ratio(vacuum)	Excellent	Excellent	n/a
Complexity of part	Infinite	mainly round	cross section
Part tolerance	Good	Good	Excellent
Material usage	Poor	Good	Excellent
Speed of production	Slow	Medium	Fast
Part quality	Good	Excellent	Excellent
Strength orientation	Excellent	Excellent	Good

CHAPTER III

EXPERIMENTAL STUDIES

III.1 MATERIALS USED IN THE STUDY

III.1.1 Unsaturated Polyester

The main driving factor for choosing low profile unsaturated polyesters were their high mechanical strength. Thus, in this study, the particular low profile unsaturated polyesters, which are known with DSM Palapreg 2273, DSM Dewilux 511.950 acronyms were chosen.

The unsaturated DSM Palapreg 2273 polyester resin derived from orthophtalic acid and glycols, dissolved in styrene. DSM Palapreg 2273 has a high viscosity and high reactivity as seen below [49]:

Viscosity, 23 °C : 2200-2700 cp

Solid Content : 65-68 %

Peak Temperature : 270 – 290 °C

Flexural Strength : 120 MPa (unfilled resin)

Tensile Strength : 70 MPa (unfilled resin)

Heat Deflection Temp.: 120 °C (unfilled resin)

The second unsaturated polyester resin, DSM Dewilux 511.950, is derived from isophtalic acid and glycols, dissolved in styrene. The properties of DSM Dewilux 511.950 is stated as follows [50]:

Viscosity, 23 °C : 1300 – 1500 cp

Solid Content : 63 -66 %

Peak Temperature : 265 – 290 °C

Flexural Strength : 100 MPa (unfilled resin)

Tensile Strength : 60 MPa (unfilled resin)

Heat Deflection Temp.: 140 °C (unfilled resin)

The viscosity of DSM Dewilux 511.950 is in medium range and has a lower reactivity than DSM Palapreg 2273.

III.1.2 Vinyl Ester

DSM ATLAC XP 810 vinyl ester was chosen because of its high reactivity and medium viscosity [51]. The physical properties are listed below:

Viscosity, 23 °C : 2000 – 2500 cp

Solid Content : 56-59 %

Peak Temperature : 265 – 290 °C

Flexural Strength : 155 MPa (unfilled resin)

Tensile Strength : 81 MPa (unfilled resin)

Heat Deflection Temp.: 145 °C (unfilled resin)

III.1.3 Epoxy Resins

III.1.3.1. Epoxy System 1

Araldite LY 1556 / Aradur 1571 / Accelerator 1573 / Hardener XB 3403 were used prepreg system based on chemical B stage [52]. The key data of epoxy system 1 is given in Table III.1. The mixing Ratio of epoxy resin system is listed in Table III.2.

Table III.1 The Key data of epoxy resin system 1

Araldite® LY 1556		
Aspect (visual)	clear, pale yellow liquid	
Viscosity at 25 °C (ISO 9371B)	10000 - 12000	[mPa s]
Density at 25 °C (ISO 1675)	1.15 - 1.20	[g/cm³]
Storage temperature	2 - 40	[°C]
Aradur® 1571		
Aspect (visual)	White viscous paste	
Viscosity at 25 °C	28000 - 40000	[mPa s]
Density at 25 °C (ISO 1675)	1.2	[g/cm³]
Storage temperature	< 8	[°C]
Accelerator 1573		
Aspect (visual)	White viscous paste	
Viscosity at 25 °C	60000 - 90000	[mPa s]
Density at 25 °C (ISO 1675)	1.08	[g/cm³]
Storage temperature	< 8	[°C]
Hardener XB 3403		
Aspect (visual)	clear liquid	
Viscosity at 25 °C	5 - 20	[mPa s]
Density at 25 °C (ISO 1675)	1.0	[g/cm³]

Table III.2 The mixing Ratio of Epoxy Resin System 1

Components, parts by weight	Ratio 1	Ratio 2	Ratio 3
Araldite LY 1556	100	100	100
Aradur 1571	23	23	23
Accelerator 1573	3	5	7
Hardner XB 3403	12	12	12

The gel time on hot plate and shelf life of epoxy resin system 1 are listed in Table III.3 and Table III.4 respectively [52]:

Table III.3 The Gel time of Epoxy Resin

	Ratio 1	Ratio 2	Ratio 3
at 110 °C [min]	17-20	13-15	12-14
at 120 °C [min]	9-11	7-9	6-7
at 130 °C [min]	5-6	3-5	3-4

Table III.4 The Shelf life of epoxy Resin System 1

	Ratio 1	Ratio 2	Ratio 3
at 23 °C [min]	> 6 weeks	> 6 weeks	> 6 weeks

III.1.3.2 Epoxy Resin System 2

Resin XU 3508/ Aradur 1571/Accelerator 1573/Hardener XB 3403 were used as prepreg system based on chemical B stage [53]. The key data of epoxy resin system 2 is gven in Table III.5. The mixing Ratio of epoxy resin system 2 is listed in Table III.6.

Table III.5 The Key data of Epoxy Resin system 2

Resin XU 3508		
Aspect (visual)	White, liquid	
Viscosity at 25 °C (ISO 9371B)	11000-20000	[mPa s]
Density at 25 °C (ISO 1675)	1.15 -1.20	[g/cm^3]
Storage temperature (See expiry date on original container)	2-40	[°C]
Aradur® 1571		
Aspect (visual)	White viscous paste	
Viscosity at 25 °C	28000-40000	[mPa s]
Density at 25 °C (ISO 1675)	1.2	[g/cm^3]
Storage temperature	< 8	[°C]
Accelerator 1573		
Aspect (visual)	White viscous paste	
Viscosity at 25 °C	60000 - 90000	[mPa s]
Density at 25 °C (ISO 1675)	1.08	[g/cm^3]
Storage temperature	< 8	[°C]
Hardener XB 3403		
Aspect (visual)	Clear liquid	
Viscosity at 25 °C	5 - 20	[mPa s]
Density at 25 °C (ISO 1675)	1.0	[g/cm^3]

Table III.6 The mixing Ratio of Epoxy Resin System 2

Components, parts by weight	Ratio 1	Ratio 2	Ratio 3
Resin XU 3508	100	100	100
Aradur 1571	23	23	23
Accelerator 1573	3	5	7
Hardner XB 3403	12	12	12

The gel time on hot plate and shelf life of epoxy resin system 2 are listed in Table III.7 and Table III.8, respectively [53].

Table III.7 The Gel time of Epoxy Resin System 2

	Ratio 1	Ratio 2	Ratio 3
at 100 °C [min]	35-40	29-33	21-25
at 110 °C [min]	17-21	14-18	10-14
at 120 °C [min]	8-12	6-10	4-8

Table III.8 The Shelf life of epoxy Resin System 2

	Ratio 1	Ratio 2	Ratio 3
at 23 °C [min]	> 4 weeks	> 4 weeks	> 4 weeks

III.1.4 Low Profile Additives

Palapreg H 852-03 and Palapreg H 1080-02 were chosen as low profile additives. Palapreg H 852-03 is a solution of modified saturated polyester, dissolved in styrene, where Palapreg H 1080-02 is a solution of a thermoplastic based on PVAc in styrene.

Palapreg H 852-03 is used to obtained high surface quality and its physical properties are listed below [54].

Viscosity, 23 °C : 150 - 175 cp

Flexural Strength : 180 MPa (filled resin)

Tensile Strength : 100 MPa (filled resin)

Palapreg H 1080-02 is used especially in sheet molding compounds or pultrusion systems. Pigmentably is limited and the physical properties are given below [55].

Viscosity, 23 °C : 3400 - 4800 cp

Flexural Strength : 210MPa (filled resin)

Tensile Strength : 85 MPa (filled resin)

III.1.5 Peroxides

Peroxan PO (tert-Butyl peroxy-2-ethylhexanoate) is used for the curing of unsaturated and vinyl ester resins. Its chemical structure is given in Figure III.1. It is liquid and purity is 98 %.

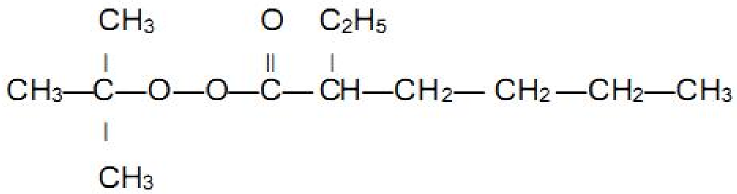


Figure III.1 The Peroxan PO Structure

PEROXAN PO is preferred for the curing of UP resin based hot press molding formulations in the temperature range from 100° to 140°C. As PEROXAN PO is high reactive peroxide, it is very suitable as a kicker in formulations for pultrusion and SMC/BMC. In combination with a cobalt accelerator 1% cobalt, PEROXAN PO is applicable for the cure of UP resins and vinyl ester resins in the temperature range of 60°C and higher [56].

CH 80 AL (1,1-Di(tert. butylperoxy)cyclohexane) is used for the curing of unsaturated and vinyl ester resins. Its chemical structure is given in Figure III.2. The purity of CH 80 AL is 80 %, solution in aliphatics.

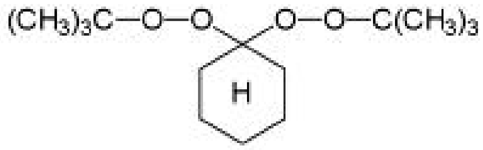


Figure III.2 The Structure of CH 80 AL

It is used for curing agent for Unsaturated Polyester and Vinyl ester resin. The usage level 0.5-2.5 % as supplied. In the range of 80-90 °C (kick off temperature) the curing rate is not very high. Short cure times of 1-3 minutes can be achieved only above 120 °C. The optimum range for hot press molding is three-fore 130-150 °C [57].

III.1.6 Inhibitor

Pergaslow PK 40 (2,6-Di-tert.butyl-p-kresol) is used as an inhibitor for retarding the gel time of resins. The chemical structure of the inhibitor is given in Figure III.3. It is solved in 40 % xylene [58].

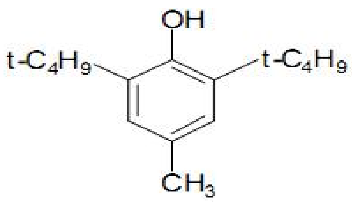


Figure III.3 The structure of inhibitor

III.1.7 Mold Release Agent

Zinc stearate is used internal mold releases in composite structures. The chemical structure of Zinc stearate is given in Figure III.4 below. Zinc stearate ($Zn(C_{18}H_{35}O_2)_2$) is a zinc soap that repels water. It is insoluble in polar solvents such as alcohol and ether but soluble in aromatic hydrocarbons (e.g., benzene and chlorinated hydrocarbons) when heated. It is the most powerful mold release agent among all metal soaps. It contains no electrolyte and has a hydrophobic effect. Its main application areas are the plastics and rubber industry where it is used as a releasing agent and lubricant which can be easily incorporated [59].

Appearance : soft, white powder

Density : 1.095 g/cm³, solid

Melting point :120–130 °C

Boiling point : decomposes

Solubility in water : insoluble

Solubility in benzene : slightly soluble

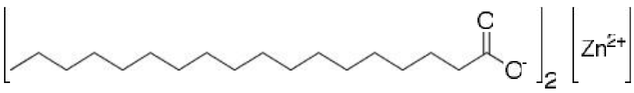


Figure III.4 The structure of Zinc Sterat

III.1.8 Shrinkage Reducer

Coethylene is spherical, microfine, polymer powders are shown in Figure III.5.

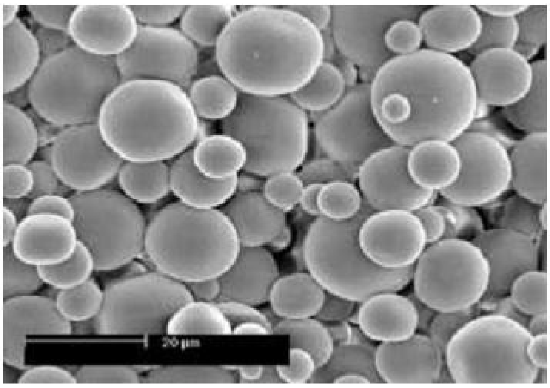


Figure III.5 The Structure of Coethylene

These powders are made from high molecular weight polymers giving them tough, rugged, strong mechanical properties. Coetyhlene is used in a variety of customer applications, including [60]:

- Low profile additive for thermosets/composites
- Pultrusion processing aids
- Dusting agent for tacky polymer surfaces

- Sintering agent/pore former
- Binding agent for particulates
- Additive for coatings and adhesives
- Additive carrier for chemicals and pigments

III.1.9 Fillers

Portflame SG 40 and Aluminium Tri Hidrat (ATH) were chosen as fillers. Portflame SG 40 is produced from carefully selected, synthetic aluminium hydroxide [61]. ATH is used in conjuction with halogen and antimony flame retardants; however, recent fire safety concerns have placed more emphasis on the reduction of toxic gas emissions. ATH fillers are also used in composites laminates for their ability to improve arc and trac resistance [32].

Typical Chemical Analysis

Al_2O_3 ratio	65 %
Na_2O	0.2 %
Fe_2O_3	0.01 %
Loss on ignition	34.5 %

III.1.10 Reinforced Fiber

CAMELYAF GLASS FIBER / SMC3 multi end roving is made from "E" glass fiber as 2400 text was selected because of its use in sheet molding compound process. Its properties are given in Table III.9 and specialties are listed below for general purpose reinforcement for manufacturing of polyester molding compounds especially for large size SMC parts. The silane based sizing is compatible with polyester resins [62].

- good unwinding,
- good strand integrity and choppability,
- none of static electricity,
- no fuzz,
- medium soluble,
- very good dispersion,
- good impregnation,

- good mechanical and surface finish properties,

Table III.9 The Properties of CAMELYAF GLASS FIBER / SMC3

Type of glass	E	Moisture content %	max. 0.15
Roving tex count (g/1000 m)	2400 ± %5	Size content %	1.25 ± 0.20
Split tex count (g/1000 m)	Nom. 80	Coupling agent	Silane
Filament diameter (μ)	Nom. 15	Resin compatibility	Polyester
Static electricity (kV)	max. ± 1	Wet-out	Medium

CAMELYAF GLASS FIBER / MAT8 chopped strand mat is made from "E" glass fiber was the second material chosen as fiber in this study. It specialties are listed as follows;

- good weight distribution,
- fast wetting out,
- minimum rolling-out,
- good impregnation,
- good drapability properties,

for general purpose hand lay-up applications. The silane based sizing is compatible with polyester resins where the properties are written in Table III.10.

Table III.10 The properties of CAMELYAF GLASS FIBER / MAT8

Type of glass	E	Resin compatibility	Polyester
Filament diameter (μ)	Nom.12	Weight per unit area (g/m2)	225 ± %7
Split tex count (g/1000 m)	30	Wet-out	Fast
Coupling agent	Silane	Length of chopped fibres (mm)	50

III.2 EQUIPMENTS AND TEST PROGRAM USED IN THE STUDY

III.2.1 DVT GE4 10 KN Machine and Devotrans Test Program

DVT GE4 10 KN and Test program (Devotrans V 1.4.1) were used to describe flexural and tensile strength and modulus. Flexural and tensile strength and modulus were measured at 23°C and 50 °C and 100 °C in heat conditions and at 20 mm/min speed rate (Figure III.6). Specimens were prepared according to TS EN ISO 14125 Fiber reinforced plastic composites- Determination of flexural properties and TS EN ISO 527-4 Determination of Tensile properties.

Figure III.6 DVT GE4 10 KN machine and DEVOTRANS TEST PROGRAM V 1.4.1

III.2.2 Charpy Impact Tester CD1 C

Charpy impact strength was carried out to using Charpy Impact Tester CD1 (Devotrans) as shown in Figure III.7. Specimens were prepared according to ISO 179 Plastics – Determination of Charpy impact properties.

Figure III.7 Charpy Impact Tester

III.2.3 Flame Characteristic Tester

The flame characteristics were carried using UL 94 flame tester as seen in Figure III.8. The flame tester equipment was manufactured for SAMİ TONGUN CO for their specific use.

The specimens were prepared according to Test for Flammability of Plastic Materials for Parts in Devices and Appliances UL 94.

Figure III.8 The Flame Characteristic Tester

III.2.4 Glow Wire Flammability Instrument

The burning behavior was carried out using Glow Wire Tester produced by COTEST (Figure III.9). The specimens were prepared according to IEC 60695-2-12 glow-wire flammability test methods [63].

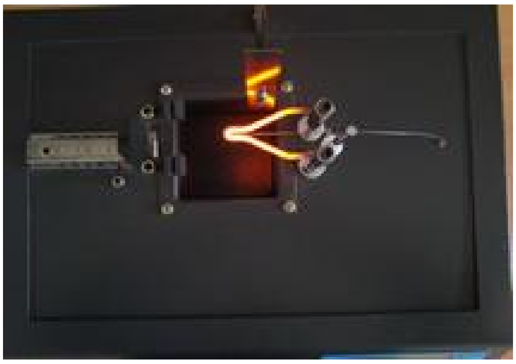


Figure III.9 The Glow Wire Tester

III.2.5 Caliper

The specimen’s dimensions were measured by using caliper bought from TEKNİKEL is shown in Figure III.10.

Figure III.10 Caliper

III.2.6 Pyknometer

The specimen's density was carried out using pyknometer (Figure III.11). The specimens were prepared according to Plastics - Methods for determining the density of non-cellular plastics - Part 1: Immersion method, liquid pyknometer method and titration method.

Figure III.11 Pyknometer

III.2.7 Sensitive Balance

The chemicals, specimens, and material were weighed by using AXIS AG 300 sensitive balance (Figure III.12).

Figure III.12 Sensitive Balance

III.2.8 Metriso C

Metriso C was used to measure surface resistivity. Surface Resistivity is the resistance to the flow of electrical current across its surface. The resistance to an electrical current is measured by electrodes on the same surface. Side view; the top inner electrode and the bottom (ground) are circular while the outer top electrode is annular [64].

Figure III.13 Metriso C

III.2.9 Pilot Dissolver and Z-Blade Mixer

The Pilot dissolver and Z- blade mixer were used to prepare the sample bulk molding compound can be seen in Figure III.14.

a) Dissolver b) Z blade mixer

Figure III.14 Pilot Dissolver and Mixer

III.2.10 Dissolver and Sheet Molding Compound Machine

High strength compounds were manufactured by using dissolver (Figure III.15 a) and sheet molding compound machine (SAMİ TONGÜN CO.) As seen in Figure III.15 b, the width of machine is 85 cm, and the length is 9 m.

a) Dissolver b) SMC machine

Figure III.15 Dissolver and SMC machine

III.2.11 Hot Pressure Molding Press

Test plate and ballistic shields were pressed by using SAMİ TONGÜN Hot Pressure Molding Pres (Figure III.16).

Figure III.16 Hot Pressure Molding Pres

III.2.12 Ballistic Test Equipment

Ballistic tests were carried out using ballistic test equipment at Afyonkarahisar 8. Main Maintenances Command (Figure IV.17).

Figure III.17 Ballistic Test Equipment [65]

Conformance tests are needed to assure the continued integrity of a previously characterized material system. The tests performed must be able to characterize each batch/lot of material so a proper assessment of critical properties of a material system can be made. These critical properties provide information on the integrity of a material system with regard to material properties, fabrication capability, and usage. Quality control in a production environment involves inspection and testing of composites in all stages of composites manufacture and part fabrication. Tests must be performed by the material supplier on the fiber and resin as separate materials, as well as on the composite material [66].

III.3 STANDARDS USED IN CHARACTERIZATION

Mechanic tests are used to measure a constant rate, impact, urgency or when exposed to tear strength of material. Existing tests are as follows;

a) Flexural strength
b) Tensile Strength
c) Impact Strength
d) Density
e) Hardness
f) Water Absorption
g) Glow Wire test

III.3.1 Flexural Strength (Method A – three point) (TS EN ISO 14125)

The method specifies to determine the flexural properties of fiber reinforced plastic composites under three point loading. In addition the method is used to investigate the flexural behavior of the test specimens and for determining the flexural strength, flexural modulus and other aspects of the flexural stress/strain relationship under the conditions defined.

The test machine shall be capable of maintaining the speed of testing, as specified in Table III.11.

Table III.11 Recommended values for the speed of testing [67]

Speed (mm/min)	Tolerance (%)
0.5	± 20
1	± 20
2	± 20
5	± 20
10	± 20
20	± 20
50	± 20
100	± 20
200	± 20
500	± 20

The specimen axis shall be in one of the principal directions. The coordinate axes for an aligned material are defined in Figure III.18. The direction parallel to the fiber axes is defined as the “1” direction and the direction perpendicular to it the “2” direction. For other materials, the 1, 2 and 3 direction are generally described by the x, y, z system of coordinates. The “1” direction is referred to as the 0 degree (0°) or longitudinal direction, and the “2” direction as the 90 degree (90°) or transverse direction [67].

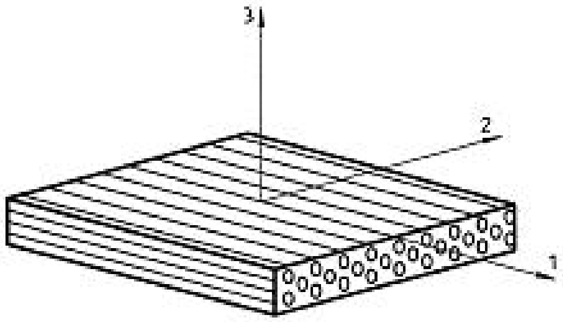


Figure III.18 Unidirectional reinforced composite plate element showing symmetry axes [67]

Specimen shall be machined from a panel prepared in accordance with relevant material specification. Five test specimens giving valid failures shall be tested. The number of measurement may be more than five if greater precision of the mean value is required. It is possible to evaluate this by means of the confidence interval.

The procedure of measurement is mentioned about step by step at below;

The test specimens of dimensions are measured as the width “b” and the thickness “h” to the nearest 1% in the center of each specimen. The mean thickness “h” of the set of specimens is calculated.

Adjust the span “L” to the within 1% of the calculated value is adjusted to comply with the best span/mean specimen thickness ratio L/h given Table III.2 for preferred specimen sizes, and measure the resulting span to better than 0.2% of the calculated value [67].

Table III.12 Preferred test specimens for three point flexure [67]

Material	Specimen length	Outer span	Width	Thickness
Class I Discontinous fibre reinforced thermoplastic	80	64	10	4
Class II Plastics reinforced with mats, contionus matting and fabrics as well as mixed formats (e.glass fiber systems)	80	64	15	4
Class III Transverse (90°) unidirectional composites; Undirectional (0°C) and multidirectional composites with 5<En/G13≤ 15 (e.g. glass fiber systems)	60	40	15	2
Class IV Unidirectional (0°C) and multidirectional composites with	100	80	15	2

5<En/G13≤ 50 (e.g. carbon fiber systems)				
Tolerans	-0 / + 10	± 1	± 0.2	± 0.2
Note : to resduce variability in data for specimens using coarse reinforcement, a specimen width of 25 mm may be used				

The span is arranged as chosen material class. The test specimen is placed symmetrically on two supports and identifies tensile face. Force is applied at mid span for three points as seen in Figure III.19. The applied force and corresponding deflection are recorded during the test.

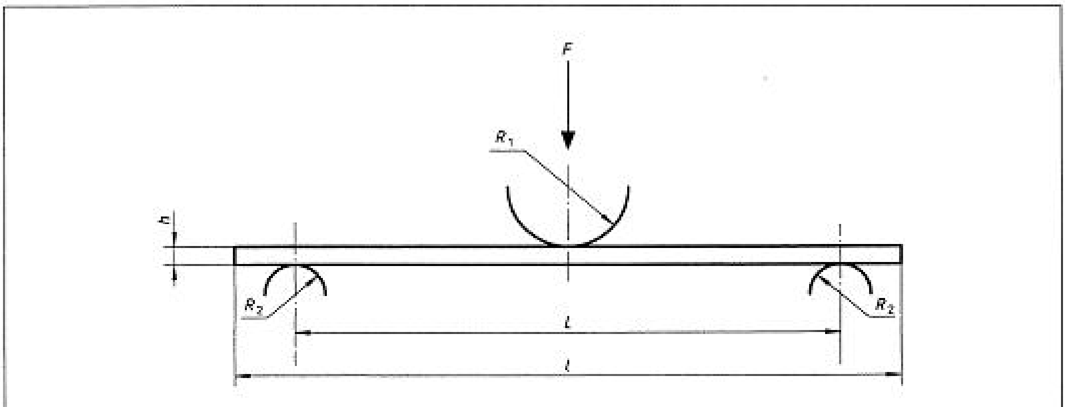


Figure 3 — Three-point loading arrangement

Figure III.19 Three point loading arrangement [67]

The Flexural stress σ_f is given by the following equation III.1 ;

$$\sigma_f = \frac{3FL}{2bh^2}$$ (Equation III.1)

σ_f is the flexural stress, in megapascals (Mpa)

F is the load in Newtons (N);

L is the span, in milimetres (mm)

h is the thickness of the specimen, in millimeters (mm)

b is the width of the specimen, in millimeters (mm)

The flexural modulus is calculated by the following equation III.2

$$E_f = \frac{L^3}{4bh^3}\left(\frac{\Delta F}{\Delta s}\right)$$ (Equation III.2)

E_f is the flexural modulus of elasticity, expressed in megapascals (MPa

Δs is the difference in deflection between s” and s’

ΔF is the difference in load F” and load F’ at s” and s’

s” and s’ are the beam mid-point deflections, in millimeters (mm) [67].

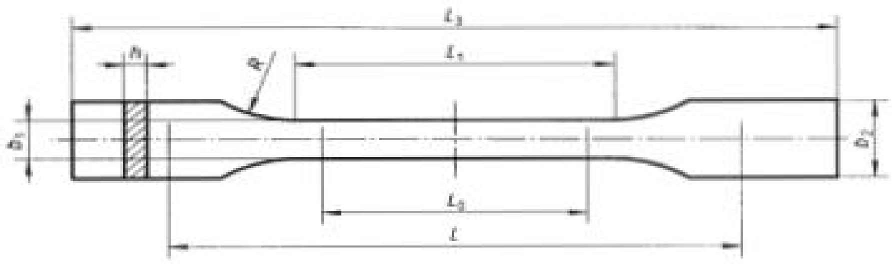
III.3.2 Tensile Strength (ISO 527-4)

The method specifies to determine the tensile properties of fiber reinforced plastic composites. In addition the method is used to investigate the tensile behavior of the test specimens and for determining the tensile strength, tensile modulus.

Three types of test specimen are specified for use ISO 527, as detailed and illustrated in Figure III.20 Type 1B and Figure III.21 (types 2 and 3).

Type 1B is for testing fiber reinforced thermoplastic. Type 1B specimens may also be used for fiber reinforced thermosets if they break within the gauge length. Type 1B may not be used for multi directional, continuous fiber reinforced materials.

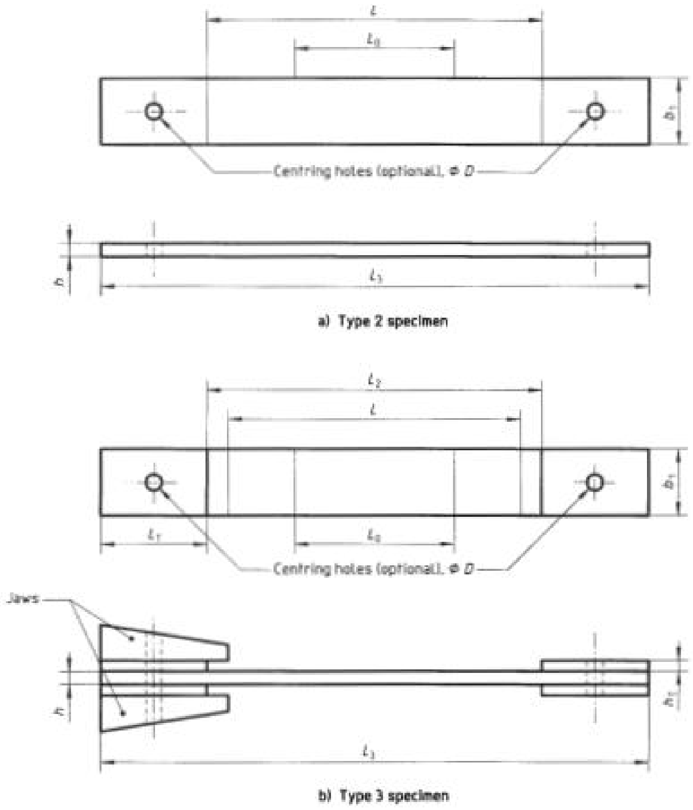
Type 2 (rectangular without end tabs) and type 3 (rectangular with bonded and tabs) are for testing fiber reinforced thermosets and thermoplastics. The preferred width of type 2 and 3 specimens is 25 mm, the thickness is between 2 mm and 10 mm [68].



Dimensions in milimetres

L_3	overall length	≥ 150
L_1	Length of narow parallel-sided portion	60 ± 0.5
R	Radius	≥ 60
b_2	Width at ends	20 ± 0.2
b_1	Width of narrow portion	10 ± 0.2
h	Thickness	2-10
L_0	Gauge length (recommended for extensometers)	50 ± 0.5
L	Initial distance between grips	115 ± 1

Figure III.20 Type 1B specimens [68]



		Dimensions in millimetre	
		Type 2	Type 3
L_3	Overall length	≥ 250	≥ 250
L_2	Length of narow parallel-sided portion	-	-
b_1	Width	25 ± 0.5 or 50 ± 0.5± 0,5	
h	Thickness	2 to 10	2 to 10
L_0	Gauge length (recommended for extensometres)	50 ± 1	50 ± 1
L	Initial distance between grips	150 ± 1	136 ± 1
L_T	Length of end tabs	-	≥ 50
h_T	Thickness of end tabs	-	1 to 3
D	Diametre of centring holes	3 ± 0.25	3 ± 0.25

Figure III.21 Type 2 and type 3 specimens [68]

The test process involves placing the test specimen in the testing machine as shown in Figure III.22 and applying tension to it until it fractures. During the application of tension, the elongation of the gauge section is recorded against the applied force. The data is manipulated so that it is not specific to the geometry of the test sample. The elongation measurement is used to calculate the engineering strain, ε, using the following equation III.3 [69];

$$\varepsilon = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}$$ (Equation III.3)

where ΔL is the change in gauge length, L_0 is the initial gauge length, and L is the final length.

The force measurement is used to calculate the *engineering stress*, σ, using the following equation III.4 :

$$\sigma = \frac{F_n}{A}$$ (Equation III.4)

where F is the force and A is the cross-section of the gauge section.

The machine does these calculations as the force increases, so that the data points can be graphed into a stress-strain curve.

Figure III.22 The Machine of Tensile Strength

III.3.3 Charpy Impact Strength (ISO 179)

The aim of this testing method is to determine characteristic fracture mechanics parameters which quantify the resistance of the material [70].

The test specimen, supported near its ends as a horizontal beam, is impacted by a single blow of a striker, with the line of impact midway between the supports, and bent at a high nominally constant, velocity. In the case of edgewise impact with notched specimens, the line of impact is directly opposite the single notch Figure III.23.

Testing is performed on either notched or unnotched specimens. The impact blow is in either the edgewise or the flat wise direction for most materials. For long fiber reinforced specimens the impact is either normal or parallel to the orientation of the fibers. Type 2 and 3 specimens are used for long fiber reinforced materials [71].

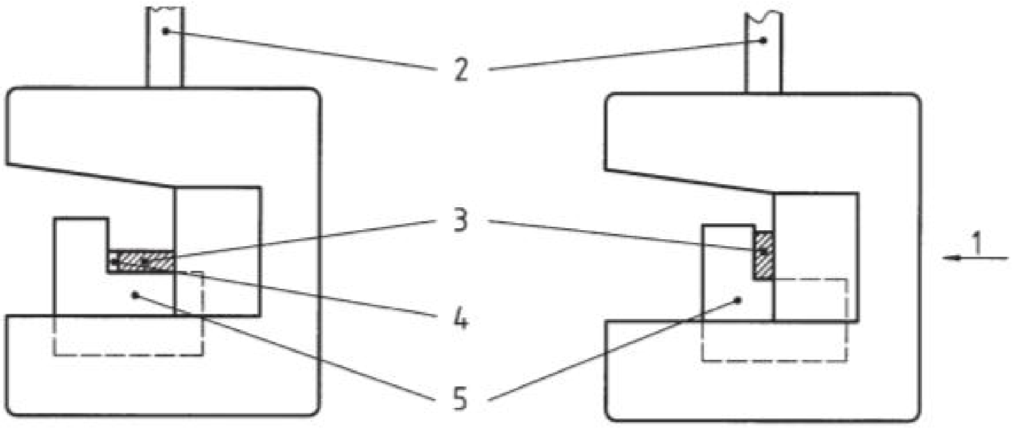


Figure III.23 Striking edge and support blocks for type 1 test specimen at the moment of impact [71]

Where

1 Direction of blow

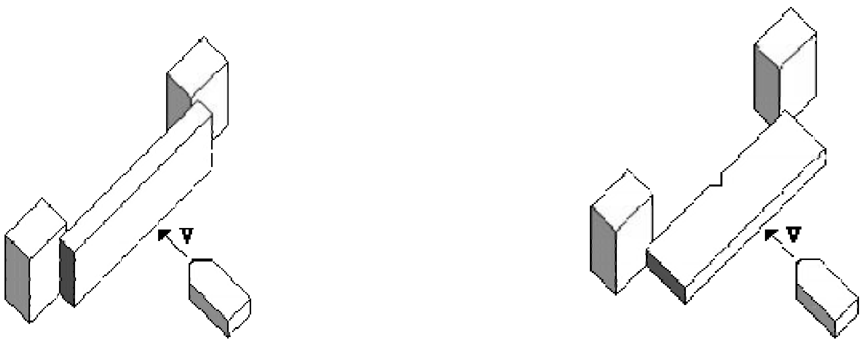
2 Rod of pendulum

3 Test Specimens

4 Notches

5 Supports

Type 1 specimens with one of three different types of notch shall be used as specified in Table III.13 and III.14 and in Figure III.24. The notch shall be located at the center of specimen [72].



Edgewise Impact Flatwise Impact

Figure III.24 The test methods of charpy impact strength [72]

Table III.13 Specimen types, dimensions and spans [71]

Specimen Type	Length[a] *l*	Width[a] *b*	Thickness[a] *h*	Span *L*
1	80 ± 2	10.0 ± 0.2	4.0± 0.2	$62^{+0.5/-0.0}$
2[b] 3[b]	25 h 11h or 13 h	10 or 5[c]	3[d]	20 h 6h or 8 h

a The specimen dimensions (thickness *h*, width *b* and length *l*) are defined according to $h \leq b < l$
b Specimen types 2 and 3 shall be used only for materials described in 6.3.2
c 10 mm for materials reinforced with a fine structure, 15 mm for those with a large stitch structure
d Preferred thicknes, If the specimen is cut from a sheet or piece, *h* shall be equal to the thickness of the sheet or piece, up to 10.2 mm

Table III.14 Method designations, specimen types, notch types and notch dimensions- Materials not exhibiting interlaminar shear fracture [71]

Method Designation	Specimen Type	Blow Direction	Notch Type	Notch base radius, r_N	Remaining Width, b_N at notch base
ISO 179-1/eU[b]	1	Edgewise	Unnotched		
			Single notch		
ISO 179-1/eA[b]			A	0.25 ± 0.05	8 ± 0.2
ISO 179-1/eB[b]			B	1.00 ± 0.05	8 ± 0.2
ISO 179-1/eC[b]			C	0.10 ± 0.02	8 ± 0.2
ISO 179-1/1fU[C]		Flatwise	Unnotched		

a If specimens are taken from sheet or products, the thickness of the sheet or product shall be added to the designation,
unreinforced specimens shall be tested with their machined surface under tension.
b Preferred method
c Especiaally for study of surface effects
Dimensions in millimetres

The Charpy impact Strength of unnotched specimens, a_{cU}, expressed in kilojoules per square metre, using the following Eq. III.5;

$$a_{cU} = \frac{E_c}{h \cdot b} \times 10^3 \qquad \text{(Equation III.5)}$$

where;

Ec   is the corrected energy, in joules, absorbed by breaking in the test specimen

h   is the thickness, in millimeters, of the test specimen

b   is the width, in millimeters, of the test specimen

III.3.4 Flammability Characteristics (UL 94)

The flammability characteristics are measured by using flammability tests. Flammability test is typically tested according to the Underwriters' Laboratories (UL) Standard UL 94 Tests for Flammability of Plastic Materials for Parts in Devices and Appliances. UL has assigned 12 different flame classifications to materials based on the results of lab-scale flame tests. The classifications, shown below, are used to distinguish a material's burning characteristics after test specimens have been exposed to a specified test flame under controlled laboratory conditions.

• Six of the classifications relate to materials commonly used in manufacturing enclosures, structural parts and insulators found in consumer electronic products (5VA, 5VB, V-0, V-1, V-2, HB). Innovative Polymers casting polyurethanes fit in this grouping.

• Three of the remaining six classifications relate to low-density foam materials commonly used in fabricating speaker grills and sound-deadening material (HF-1, HF-2, and HBF).

• The last three classifications are assigned to very thin films, generally not capable of supporting themselves in a horizontal position (VTM-0, VTM-1, and VTM-2). These are usually assigned to substrates on flexible printed circuit boards [73].

To test a plastic material, molded specimens are oriented in either a horizontal or vertical position and subjected to a defined flame ignition source for a specified time period.

III.3.4.1 Horizontal Burning Test (HB)

A specimen is supported in a horizontal position and is tilted at 45°. A flame is applied to the end of the specimen for 30 seconds or until the flame reaches the 1 inch mark. If the specimen continues to burn after the removal of the flame, the time for the specimen to burn between the 1 and 4 inch marks are recorded. If the specimen stops burning before the flame spreads to the 4 inch mark, the time of combustion and damaged length between the two marks is recorded. Three specimens are tested for each thickness. Figure III.25 [74].

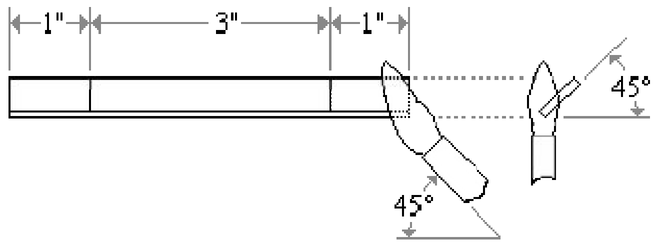


Figure III.25 The Horizontal Burning Tests [74]

Table III.25 The Horizontal Test Requirements [74]

Horizontal Rating	Requirements
HB	Specimens must not have burning rate greater than 1.5 inches/minute for thicknesses between 0.120 and 0.500 inches and 3 inches/minute for thicknesses less than 0.120 inches. Specimens must stop burning before the flame reaches the 4 inch mark.

III.3.4.2 Vertical Burning Tests (V0-V1-V2)

A specimen is supported in a vertical position and a flame is applied to the bottom of the specimen as specified in Figure III.26. The requirements of the vertical burning test are listed in Table III.26. The flame is applied for ten seconds and then removed until flaming stops at which time the flame is reapplied for another ten seconds and then removed. Two sets of five specimens are tested. The two sets are conditioned under different conditions [74].

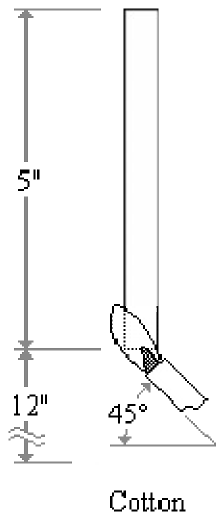


Figure III.26 The Vertical Burning Test [74]

Table III.26 The Vertical Burning Requirements [74]

Vertical Rates	Requirements
V0	Specimens must not burn with flaming combustion for more than 10 seconds after either test flame application. Total flaming combustion time must not exceed 50 seconds for each set of 5 specimens. Specimens must not burn with flaming or glowing combustion up to the specimen holding clamp. Specimens must not drip flaming particles that ignite the cotton. No specimen can have glowing combustion remain for longer than 30 seconds after removal of the test flame.
V1	Specimens must not burn with flaming combustion for more than 30 seconds after either test flame application. Total flaming combustion time must not exceed 250 seconds for each set of 5 specimens. Specimens must not burn with flaming or glowing combustion up to the specimen holding clamp. Specimens must not drip flaming particles that ignite the cotton. No specimen can have glowing combustion remain for longer than 60 seconds after removal of the test flame.
V2	Specimens must not burn with flaming combustion for more than 30 seconds after either test flame application. Total flaming combustion time must not exceed 250 seconds for each set of 5 specimens. Specimens must not burn with flaming or glowing combustion up to the specimen holding clamp. Specimens can drip flaming particles that ignite the cotton. No specimen can have glowing combustion remain for longer than 60 seconds after removal of the test flame.

III.3.5 Ballistic Characterization

The ballistic resistant materials used to fabricate armor include metals, ceramics, transparent glazing, fabric, and fabric-reinforced plastics; they are used separately or in combination, depending upon the intended threat protection. The ballistic threat posed by a bullet depends, among other things, on its composition, shape, caliber, mass, and impact velocity. Because of the wide variety of cartridges available in a given caliber, and because of the existence of hand loads, armors that will defeat a standard test round may not defeat other loadings in the same caliber.

Ballistic resistant protective materials covered by this standard are classified into five types, by level of performance.

III.3.5.1 Type I Test Weapons and Ammunition

22 LR; The test weapon may be a 22-caliber handgun or test barrel. The use of a handgun with a 10 to 12 cm (6 to 6.5 in) barrel is suggested. Test bullets shall be 22 Long Rifle High Velocity lead, with nominal masses of 2.6 g (40 gr) and measured velocities of 320 – 12 m (1050 – 40 ft) per second.

38 Special ; The test weapon may be a 38 Special handgun or test barrel. The use of a handgun with a 15 to 16.5 cm (6 to 6.5 in) barrel is suggested. Test bullets shall be 38 Special round-nose lead, with nominal masses of 2.6 g (158 g) and measured velocities of 259 – 15 m (850 – 50 ft) per second.

III.3.5.2 Type II-A Test Weapons and Ammunition

Lower Velocity 357 Magnum ; The test weapon may be a 357 Magnum handgun or test barrel. The use of a handgun with a 10 to 12 cm (4 to 4.75 inc) barrel is suggested. Test bullets shall be 357 Magnum jacketed soft point, with nominal masses of 10.2 g (158 g) and measured velocities of 381 – 15 m (1250 – 50 ft) per second.

Lower Velocity 9 mm ; The test weapon may be a 9 mm handgun or test barrel. The use of a handgun with a 10 to 12 cm (4 to 4.75 in) barrel is suggested. Test bullets shall be 9 mm full metal jacketed, with nominal masses of 8.0 g (124 gr) and measured velocities of 332 – 12 m (1090 – 40 ft) per second.

III.3.5.3 Type III-A Test Weapons and Ammunition

44 Magnum ; The test weapon may be a 44 Magnum handgun or test barrel. The use of a handgun with a 14 to 16 cm (5.5 to 6.25 in) barrel is suggested. Test bullets shall be 44

Magnum, lead semiwadcutter with gas checks, nominal masses of 15.55 g (240 gr), and measured velocities of 426 – 15 m (1400 – 50 ft) per second.

Submachine Gun (SMG) 9 mm ; The test weapon may be a 9 mm SMG or test barrel. The use of a test barrel with a 24 to 26 cm 9.5 to 10.25 in) barrel is suggested. Test bullets shall be 9 mm full metal jacketed, with nominal messes of 8.0 g (124 gr) and measured velocities of 426 – 15 m (1400 – 50 ft) per second.

III.3.5.4 Type III Test Weapon and Ammunition

The test weapon may be a rifle or a test barrel chambered for 7.62-mm (308 Winchester) ammunition. The use of a rifle with a barrel length of 56 cm (22 in) is suggested. Test bullets shall be 7.62 mm full metal jacketed (U.S. military designation M80) with nominal masses of 9.7 g (150 g) and measured velocities of 838 – 15 m (2850 – 50 ft) per second.

III.3.5.5 Type IV Test Weapon and Ammunition

The test weapon may be a rifle or a test barrel chambered for 30–06 ammunition. The use of a rifle with a barrel length of 56 cm (22 in) is suggested. Test bullets shall be 30 caliber armor piercing (U.S. military designation APM2), with nominal masses of 10.8 g (166 gr) and measured velocities of 868 – 15 m (2850 – 50 ft) per second.

Table III.27 Type of Ballistic Level [75]

Armor Type	Test Ammunition	Nominal Bullet Mass	Suggested Barrel Length	Required Bullet Velocity	Required Hits Per Armor Specimen	Permitted Penetrations
I	22 LRHV Lead	2.6 g 40 gr	15 to 16.5 cm 6 to 6.5 in	320 ± 12 m/s 1050 ± 40 ft/s	5	0
	38 Special RN Lead	10.2 g 158 gr	15 to 16.5 cm 6 to 6.5 in	259 ± 15 m/s 850 ± 50 ft/s	5	0
II-A	357 Magnum JSP	10.2 g 158 gr	10 to 12 cm 4 to 4.75 in	381 ± 15 m/s 1250 ± 50 ft/s	5	0
	9 mm FMJ	8.0 g 124 gr	10 to 12 cm 4 to 4.75 in	332 ± 12 m/s 1090 ± 40 ft/s	5	0
II	357 Magnum JSP	10.2 g 158 gr	15 to 16.5 cm 6 to 6.5 in	425 ± 15 m/s 1395 ± 50 ft/s	5	0
	9 mm FMJ	8.0 g 124 gr	10 to 12 cm 4 to 4.75 in	358 ± 12 m/s 1175 ± 40 ft/s	5	0
III-A	44 Magnum Lead SWC Gas Checked	15.55 g 240 gr	14 to 16 cm 5.5 to 6.25 in	426 ± 15 m/s 1400 ± 50 ft/s	5	0
	9 mm FMJ	8.0 g 124 gr	24 to 26 cm 9.5 to 10.25 in	426 ± 15 m/s 1400 ± 50 ft/s	5	0
III	7.62 mm 308 Winchester FMJ	9.7 g 150 gr	56 cm 22 in	838 ± 15 m/s 2750 ± 50 ft/s	5	0
IV	30-06 AP	10.8 g 166 gr	56 cm 22 in	868 ± 15 m/s 2850 ± 50 ft/s	1	0
Special Requirement (see sec. 2.2.7)*	*	*	*	*		

AP - Armor Piercing; LRHV - Long Rifle High Velocity; FMJ - Full Metal Jacket; RN - Round Nose; JSP - Jacketed Soft Point; SWC - Semi-Wadcutter

* These items must be specified by the user. All of the items must be specified.

Ballistic resistance test specimen is conditioned at a temperature of 20 to 28 °C for at least 24 h prior to test. The triggering devices is placed 2 and 3 m (6.6 and 9.8 ft), respectively from the muzzle of the test weapon as shown in Figure III.27 and arrange them so that they are defined planes perpendicular to the line of flight of the bullet. The distance is measured between them with an accuracy of 1.0 mm. the time of flight is used and the distance is measured to calculate the velocity of each test round. After the specified test weapon has been supported, leveled, and positioned, fire one or more retest rounds (as needed) through a witness plate to determine the point of impact. The test specimen is placed in the support fixture and positions it 5 m (16 ft) from the muzzle of the test weapon. Then position an unperforated witness plate 15 cm (6 in) beyond the test specimen. A test is fired and recorded the velocity of the bullet as measured by the choronograph. The witness plate is examined to determine penetration. The specimen is examined to see if the bullet made a fair hit. There is no penetration occurred, the test specimen is reposition and repeated the procedure with additional test rounds until the test is completed [75].

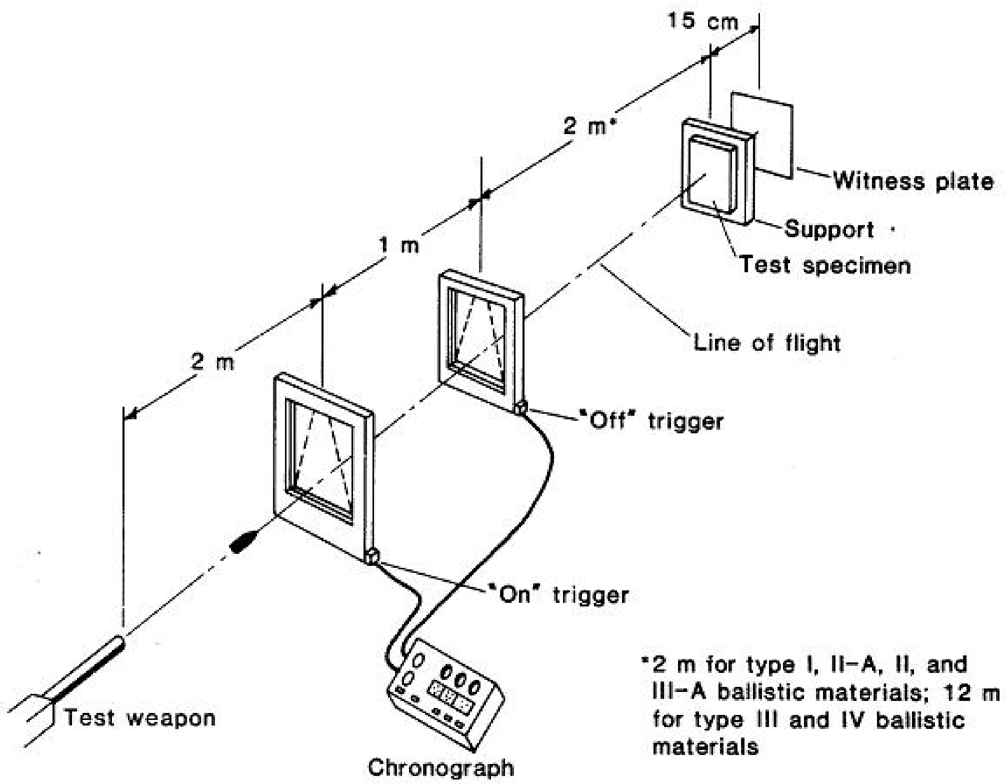


Figure III.27 The Ballistic Test System [75]

N.K Naik and P.Shiraro investigated on ballistic impact behavior of two dimensional woven fabric composites. Ballistic impact behavior of plain was compared weave E-glass/ epoxy and till weave T300/epoxy composites. Different damage and energy absorbing mechanism during ballistic impact had been identified. Energy absorbed by various mechanisms is calculated for a given mass and velocity of the projectile. Analytically predicted ballistic limit was between 158 and 159 m/s. E-glass/epoxy, complete perforation did not take place at V_1= 158 m/s whereas with V_1= 159 m/s, complete perforation taken place with exit velocity of 54 m/s. The experimentally obtained ballistic limit was V_{50} =150m/s. For the case of T300 carbon/epoxy, complete perforation did not take place with V_1= 82 m/s whereas with V_1= 83 m/s, complete perforation taken place with exit velocity of 18 m/s. The above results were with mp = 2.8 g, d = 5 mm and h = 2 mm. The ballistic limit was much higher for E-glass/epoxy than for T300 carbon/epoxy. This was because of higher energy absorbed by E-glass/epoxy than by T300 carbon/epoxy was for high strain rate loading. Shear plugging strength for E-glass/epoxy was much higher than that for T300 carbon/epoxy.They obtained the result that ballistic limit is higher for E-glass/epoxy than for T300 carbon/epoxy. For E-glass/epoxy, energy absorbed by secondary yarn deformation and tensile failure of primary yarn are the main energy absorbing mechanisms. For T300 carbon/epoxy, the main energy absorbing mechanisms are the secondary yarn deformation and shear plugging [76].

N.K Naik and A.V Doshi studied on ballistic behavior of typical woven fabric E glass/epoxy thick composites. They determined specifically energy absorbed by different mechanisms, ballistic limit velocity and contact duration. The prediction of ballistic impact behavior of thick composites was analyzed by using analytical method. The analytical method wass based on wave theory and energy balance between the projectile and the target. The analytical formulation AIAA J 2005;43(7):1525–36 of was used to determined ballistic impact behavior. Analytical predictions were compared with typical experimental results. A good match between analytical predictions and experimental results were observed. Further, effect of incident ballistic impact velocity on contact duration and residual velocity, effect of projectile diameter and mass on ballistic limit velocity and effect of target thickness on ballistic limit velocity and contact duration are studied. It was observed that shear plugging was the major energy absorbing mechanism. The experimental ballistic limit velocity for the case of 5 mm thickness was 148 m/s and for the case of 4 mm thickness it was 137 m/s. When the experiment was carried out with the target thickness of 7 mm, complete penetration did not take place even with the incident ballistic impact velocity of 173 m/s [77].

M.Mamivand and G.H Liaghat studied on a model for ballistic impact on multi- layer fabric targets. An analytical model had been developed for ballistic behavior of two dimensional woven fabric composites of interest in body armor applications. Each thin layer was assumed to have plain weave with linear- elastic mechanical properties. The penetration process of flat faced cylindrical projectiles based on conservation of momentum and wave theory was simulated by this model. Using the analytical formulation, ballistic limit, surface radius of the cone formed and projectile velocity during perforation were predicted for typical multi-layer woven fabric. The results obtained from the present model showed that ballistic limit for constant number of layers, when increasing layer spacing would decrease. Further increases in the gaps between layers did not have any effect on the performance of the armor. In thick armors fracture in layers has started at a velocity much less than the ballistic limit velocity. In a thin one (with same number of layers) it has started at a velocity near ballistic impact velocity and the total layers fracture happened in a shorter time [78].

E. DeLuca, J. Prifti, W. Betheney, S. C. Chou studied on ballistic impact damage of S-2 glass reinforced plastic structural armor. Different sizes of S 2-glass-fabric reinforced plastic laminate plates were tested ballistically by impacting the plates with two different sizes of fragment simulating. They produced laminates by using S 2 glass woven roving in a polyester resin matrix with resin content 32 ± 2% by weight. Targets of a GRP panel were prepared 20 x 20 in in size. The impacted specimens were examined with computed tomography to determine the extent of damage in the specimens, and then those specimens were tested in compression until failure. The correlation between the failure load and the extent of damage in terms of average damage fraction was presented and discussed [79].

CHAPTER IV. EXPERIMENTAL STUDIES

Experimental studies carried out in this thesis can be classified mainly in seven groups which are specified in Table IV.1.

Table IV.1 The conducted experimental studies

	Experiments
1	Determination of HMC and BMC formula
2	Determination of Resins
3	Determination of Low Profile Additives
4	Production of HMC
5	Compression Molding (determination temperature and Pressure parameters)
6	Investigated Mechanical Properties
7	Investigated Ballistic Characterization

IV.1 FORMULA DETERMINATION

Different types of formulas are used in polymer shield industry and are based on types of resin and glass fiber ratio. Products with high mechanical properties, being fireproof and bulletproof are desired. Considering the desire of the industry and literature search, it was concluded that the formulation should include also low profile additive and flame retardant fillers besides resin and glass fiber.

Then, the formulation is prepared with the ratios given in Table IV.2 which are taken directly from the data sheet of the resin.

Table IV.2 The formulation

Materials	%
Resin	30
LP Additive (H852/H 1080)	9.2
Peroxide	0.6
Inhibitor	0.02
Filler	10.6
Glass fiber	50.4
Total	100

IV.2 DETERMINATION OF RESINS

It is well-known that one of the most important parameters in the polymerization of resins is the cure time. Since drastic changes occur in the rheological properties after the cure time. Thus, any information about the cure time will undoubtedly have practical value especially in industrial applications. For instance, the curing time is critically important to evaluate the appropriate composite system and determine the optimum working conditions of hot presses. For this reason, first curing time investigations were conducted to determine the resins.

IV.2.1 Unsaturated Polyesters and Vinyl Ester

DSM Palapreg 2273-01 and DSM Dewilux 511.950 were chosen as low profile unsaturated polyesters. DSM Atlac XP 810 was chosen as vinyl ester resin. As mentioned above, resins' cure time is important to arrange hot press mold parameters. The formulation ratios given in Table IV.3 were used to determine curing time of the resins. Cure times were measured by using oil bath with temperature at 140 °C. In Figure IV.1 cure time as a function of temperature is given.

Table IV.3 The Formulation Chart

%	Material
98.3	Resin
1.6	Peroxide
0.06	Inhibitor
100.0	Total

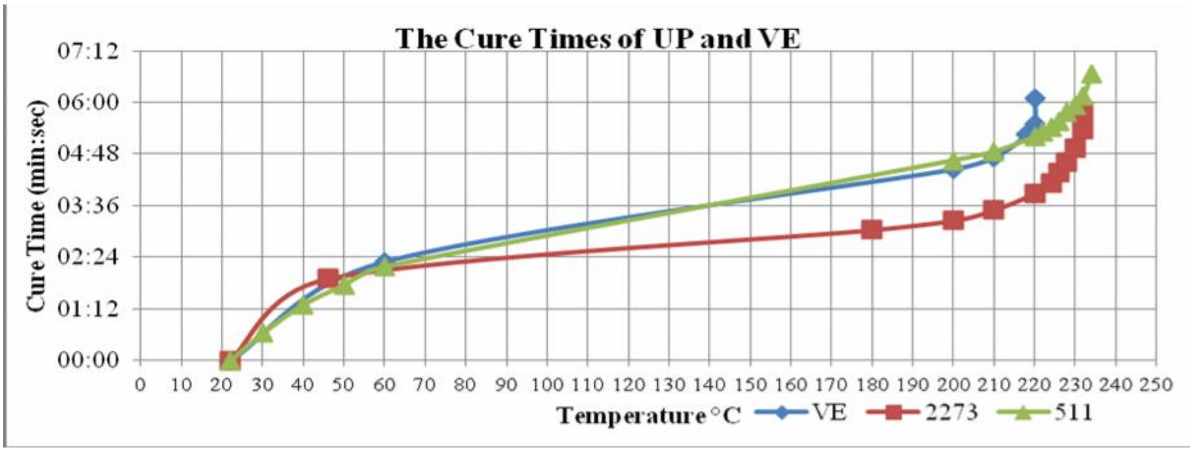


Figure IV.1 The cure times of unsaturated polyester and vinyl ester.

As it is seen in Figure IV.1, the cure time behavior of all three systems are same. Although, DSM PALAPREG 2273 (UP) has the fastest curing time, it was not considered to be compatible with DSM ATLAC XP 810 (VE). As a result, DSM PALAPREG 511-950 (UP) had almost the same curing time. Another good match was also obtained with the curing temperature for DSM PALAPREG 511-950 (UP) and DSM ATLAC XP 810 (VE). These results were summarized in Table IV.4.

Table IV.4 The Cure Times and Peak Exotherm Result of Low Profile unsaturated Polyester

	CURE		PEAK EGZOTERM	
	TIME	°C	TIME	MAX °C
DSM ATLAC XP 810 (VE)	02:18	60	06:06	220
DSM PALAPREG 511-950 (UP)	02:11	60	06:39	234
DSM PALAPREG 2273 (UP)	01:54	46	05:48	232

As it is seen clearly in Table IV.4, DSM PALAPREG 511-950 unsaturated polyester and DSM ATLAC XP 810 vinyl ester were chosen because of their same gelation time at same temperature.

IV.2.2 Epoxy Resins

As discussed in the previous section Araldite LY 1556 / Aradur 1571 / Accelerator 1573 / Hardener XB 3403 were taken to be epoxy system 1 and Resin XU 3508/ Aradur 1571/Accelerator 1573/Hardener XB 3403 were taken to be epoxy system 2. Epoxy resins systems should support sheet molding compound criteria as follows;

a) Have shorter curing time,
b) Be able to make bond with glass fiber,
c) To be separable from PV/PA protector film before molding,

d) Have high mechanical properties.

The epoxy systems in this study were investigated in respect with these criteria.

First, the mixing ratio of epoxy system 1 given in Table III.2 and III.6 were prepared according to the datasheet to determine the mentioned criteria above.

IV.2.2.1 Determining Cure Times

Cure times were measured by using oil bath with temperature 140 °C. The cure time as a function of temperature for the two different epoxy systems were shown in Figure IV.2.

As shown in Figure IV.2, epoxy system 2 has longer cure time than epoxy system 1, however cure temperature was 10 °C below. Table IV.5 shows the cure information along with peak exotherms.

Table IV.5 The Cure Times and Peak Exotherm Results of Epoxy Systems

	CURE		PEAK EXOTHERM	
	TIME	°C	TIME	MAX °C
Epoxy System 1	05:37	130	07:48	310
Epoxy System 2	06:04	120	11:12	336

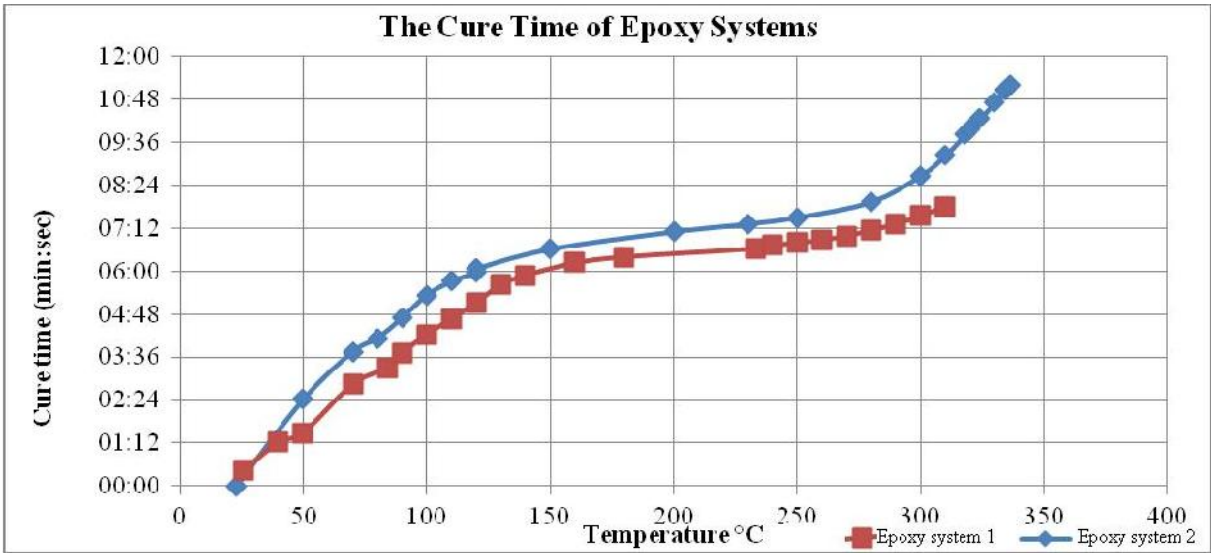


Figure IV.2 The Cure Time of Epoxy Systems

IV.2.2.2 Preparing Laminate

CAMELYAF Mat 8 glass fiber was cut for 4 pieces as 200 x 150 mm dimensions length and width, respectively, weighing 24 g. The resin mixtures were prepared for resin transfer to mats. The mats were bond (wet) with each of epoxy resin systems. Each plies were laminated via resin transfer methods by roll and put over and over. The total weights of glass fiber and epoxy resin were 96 g.

The laminates were then placed inside two protector PA/PE film to determine whether or not the laminates have the separability from the film.

The separability from the protector film was observed in 5 days for each epoxy systems. As can be clearly seen in Figure IV.3 that the epoxy system 1 did not gain the separability property even though five days of waiting time, where epoxy system 2 has been separated from the protector film in 2 days.

a) Epoxy system 1 b) Epoxy system 2

Figure IV.3 The laminate separability from protector film

IV.2.2.3 Determining of Mechanical Properties of Epoxy Resin Systems

The epoxy laminates were cured in oven at 135 °C and under 15 kg pressure. The results showed that epoxy resin system 2 was higher than epoxy system 1 in flexural, tensile, and charpy impact strengths. The results were shown in Table IV.6. The pictures of cured laminates were given in Figure IV.4. The flexural and tensile strengths for the two epoxy systems are presented in CD attached to the thesis.

a) Epoxy Resin System1 b) Epoxy Resin System 2

Figure IV.4 The Epoxy Laminates

Table IV.6 The Mechanical Properties of epoxy Resin Systems (See CD)

	Unit	Standards	Epoxy System 1	Epoxy System 2
Flexural Strength	N/mm^2	TS EN ISO 1412	157.4	199
Tensile Strength	N/mm^2	TS EN ISO 527-4	113.2	121.4
Charpy Impact Strength	kj/m^2	ISO 179	60	68.1

The criteria mentioned above has been summarized in the following Table IV.7 were investigated for epoxy resin systems.

Table IV.7 The Results of Epoxy Resin System

Criteria	**Epoxy Resin System 1**	**Epoxy Resin System 2**
Cure Time *(min: sec)*	05:37	06:04
Cure Time Temperature *(°C)*	130	120
Peak Exotherm *(°C)*	310	336
Separability From the Protector Film	No	Yes
Flexural Strength *(N/mm^2)*	157.4	199
Tensile Strength *(N/mm^2)*	113.2	121.4
Charpy Impact Strength *(kj/m^2)*	60	68.1

It was concluded that the epoxy resin system 2 should be used in HMC manufacturing. The main driving reason to select epoxy system 2 was the separability from the protector films. Since the process used to obtain HMC is realized in two protector films. The films were then peeled off before molding.

IV.2.3 Determining Low Profile Additives

Low profile systems are useful on surface smoothness, internal cracking resistance and mechanical properties. Low profile DSM Dewilux 511.950 and DSM Palapreg 2273-01 as polyester resins were used and compared with DSM Atlac XP 810 as vinyl ester resin. Moreover DSM Palapreg H1080-01 as polyvinyl acetate and DMS Palapreg H852-03 as saturated polyester are used as low profile additive. Bulk molding compound process was used to determine mechanical properties. Products were produced according to prepared formulation Table IV.2. Materials were filled in the mixing vessel respectively and in specific time. Mixing processing was done in pilot dissolver. Reinforced glass fiber was added into z mixer. Compounds were mixed in determined time and mixing ways in z mixer. Produced bulk molding compounds (BMC) were matured 10 days at 25 °C temperature. Bulk molding compounds were pressed in hot press mold. The pres parameters that lower mold temperature was 141°C, upper mold temperature was 141°C, mold pressure 100 bar and molding time 3 minutes. Plates were formed 200 x 200 x 3 mm dimensions in hot press mold. Two plates were pressed from each of bulk molding compounds. Plates were cut according to the ISO standards.

Compared table and graphs showed that DSM Palapreg H1080-01 was supported high mechanical strength with DSM Dewilux 511.950 tests were listed as follows:

a) Flexural Strength and modulus
b) Tensile Strength and modulus
c) Charpy Impact Strength
d) Hardness
e) Water Absorbtion
f) Shrinkage in Mold
g) Density
h) Surface Resistivty
i) Glow wire Test

a) Flexural Strength and Modulus

Flexural Strength and modulus were tested according to TS EN ISO 14125 at different temperature condition by using DVT GE4 10 KN machine and DEVOTRANS TEST PROGRAM V 1.4.1 Each specimens were prepared as for method A (three point flexure) class II . Specimens dimension is 64 (± 1) outer span x 15 (± 0.5) width x 4 (± 0.2) mm thickness (See CD) [67]

Table IV. 8 The Flexural Strength at 23 °C

		UNIT	**BSE 1052**	**BSE 1080**	**BSE 1152**	**BSE 1180**	**BSE 7352**	**BSE 7380**
Flexural Strength at 23°C	Max Force Fmax	(N)	155.3	159.2	134	161	114.7	156
	Max Deformation Force	ΔI Mm	3.79	3.28	3.83	4.15	3.61	4.11
	Max Strength Force	σZB N/mm²	275.3	293.3	243.4	273	205.6	262.7
	E- modul at 23 °C	N/mm²	22833	32392	24237	21795	21639	20659

Table IV.9 The Flexural Strength at 50 °C

		UNIT	**BSE 1052**	**BSE 1080**	**BSE 1152**	**BSE 1180**	**BSE 7352**	**BSE 7380**
Flexural Strength at 50°C	Max Force Fmax	(N)	142	131.5	83.8	137	112.7	137
	Max Deformation Force	ΔI Mm	4.27	4.13	3.55	4.17	3.29	4.26
	Max Strength Force	σZB N/mm²	239.2	234.1	147.9	239.2	193.8	233
	E- modul at 50 °C	N/mm²	18271	19125	14924	20798	20156	19100

Table IV.10 The Flexural Strength at 100 °C

		UNIT	**BSE 1052**	**BSE 1080**	**BSE 1152**	**BSE 1180**	**BSE 7352**	**BSE 7380**
Flexural Strength at 100°	Max Force Fmax	(N)	132	106	60.7	101.7	82.7	78.7
	Max Deformation Force	ΔI Mm	3.86	3.54	2.82	3.43	3.28	2.70
	Max Strength Force	σZB N/mm²	219.2	178.4	106.3	163.9	141.1	134.3
	E- modulus at 100 °C	N/mm²	19921	18386	14669	19667	15163	14812

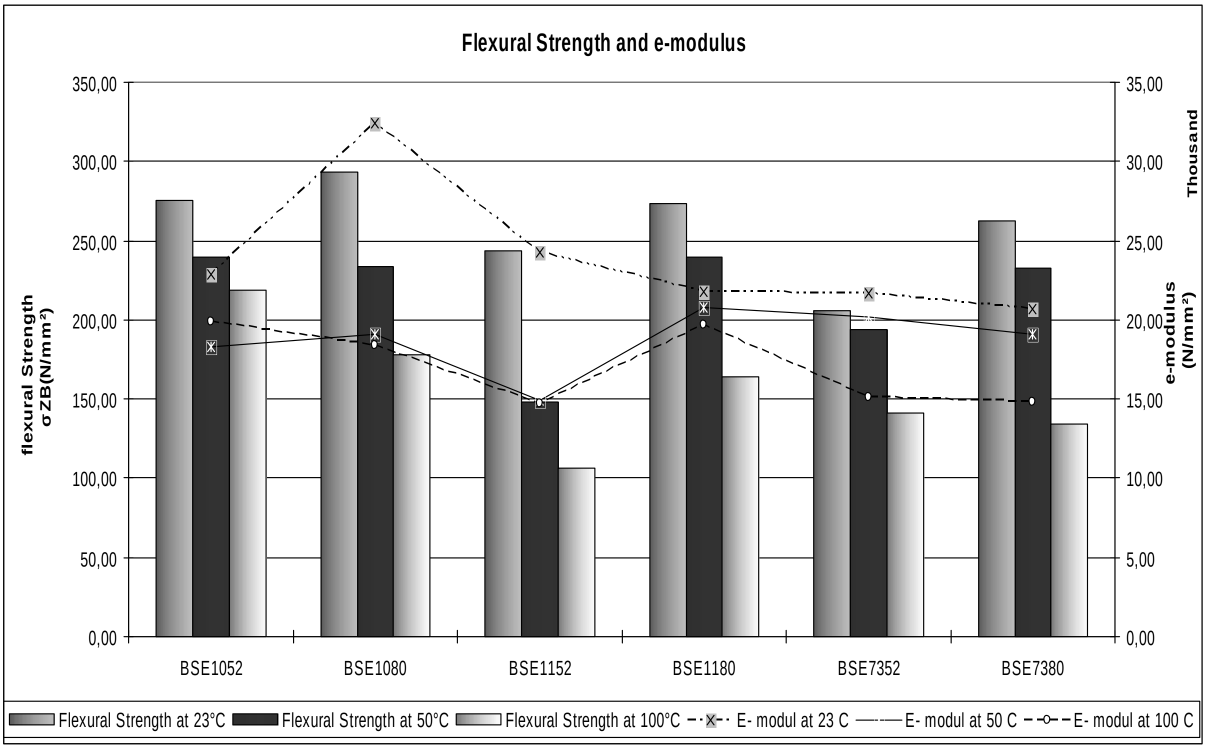


Figure IV.5 The Flexural Strength and Modulus of Low Profile Systems

b) Tensile Strength and Modulus

The Tensile strength and modulus were tested according to TS EN ISO 527-4 at different temperature condition by DVT GE4 10 KN machine and DEVOTRANS TEST PROGRAM V 1.4.1. Each specimen was prepared as for method A (three point flexure) class II. Specimens dimension is 150 (± 1) length x 10 (± 0.5) width x 4 (± 0.2) mm [68].

Table IV.11 Tensile Strength and modulus at 23 °C

		UNIT	BSE 1052	BSE 1080	BSE 1152	BSE 1180	BSE 7352	BSE 7380
Tensile Strength at 23 °C	**Max Force Fmax**	(N)	1535	1680	1431.5	1490.4	816.8	1328
	Max Deformation Force	ΔI Mm	1.17	1.24	1.16	1.14	0.74	0.34
	Max Strength Force	σZB N/mm²	36.9	40	35.5	34.8	20	31.3
	Tensile Strength	(N)	1535	1680	1431	1490	870.4	992
	E- Modulus	N/mm²	6076	7017	5469	7202	3284	5792

Table IV.12 Tensile Strength and modulus at 50 °C

		UNIT	BSE 1052	BSE 1080	BSE 1152	BSE 1180	BSE 7352	BSE 7380
Tensile Strength at 50 °C	**Max Force Fmax**	(N)	909.6	1311.6	868.4	1760.4	678.8	1252
	Max Deformation Force	ΔI mm	1.00	1.02	0.74	1.80	0.75	1.45
	Max Strength Force	σZB N/mm²	21.4	31.5	21.9	41.4	16	29.5
	Tensile Strength	(N)	1068.8	1311.6	868.4	1897.2	722	1348.3
	E- modulus	N/mm²	4763	7025	6807	4997	3570	5244

Table IV.13 Tensile Strength and modulus at 100 °C

		UNIT	**BSE 1052**	**BSE 1080**	**BSE 1152**	**BSE 1180**	**BSE 7352**	**BSE 7380**
Tensile Strength at 100 °C	**Max Force Fmax**	(N)	1516.8	1284	796.8	1307.3	722.5	822.4
	Max Deformation Force	ΔI mm	1.60	1.35	1.20	1.41	0.99	1.10
	Max Strength Force	σZB N/mm²	38.5	32.7	20.1	31.6	18.2	19.4
	Tensile Strength	(N)	1516.8	1284	866.8	1307.3	722.5	841.6
	E- Modulus	N/mm²	3780	5160	40511	5080	3868	3085

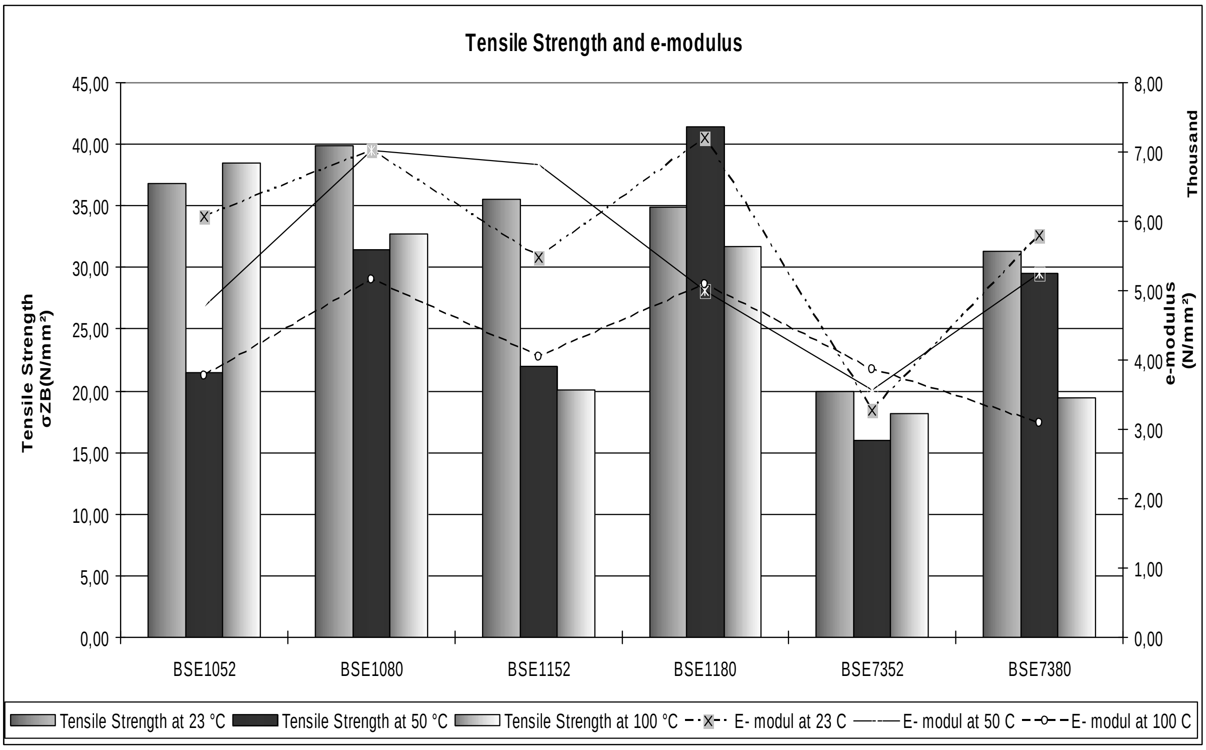


Figure IV.6 Tensile Strength and modulus for Low Profile Systems

c) Charpy Impact Strength

Charpy Impact Strength was tested according to ISO 179 in different times by DVT CD-I machine. Each specimen was prepared as for method ISO 179-1/1eU unnotched type. Specimen dimensions are 80 ± 2 mm length x 10 ± 2 mm width x 4 ± 0.2 mm thickness [68].

Table IV.14 Charpy Impact Strength of Low Profile Systems

kJ/m^2	**BSE 1052**	**BSE 1080**	**BSE 1152**	**BSE 1180**	**BSE 7352**	**BSE 7380**
Charpy Impact strength 10 day	49.0	35.4	43.3	49.7	45.1	40
Charpy Impact strength 20 day	46.4	51.1	36.2	46.6	33.2	38.7
Charpy Impact strength 40 day	25	27.5	19.2	23	27	30.9

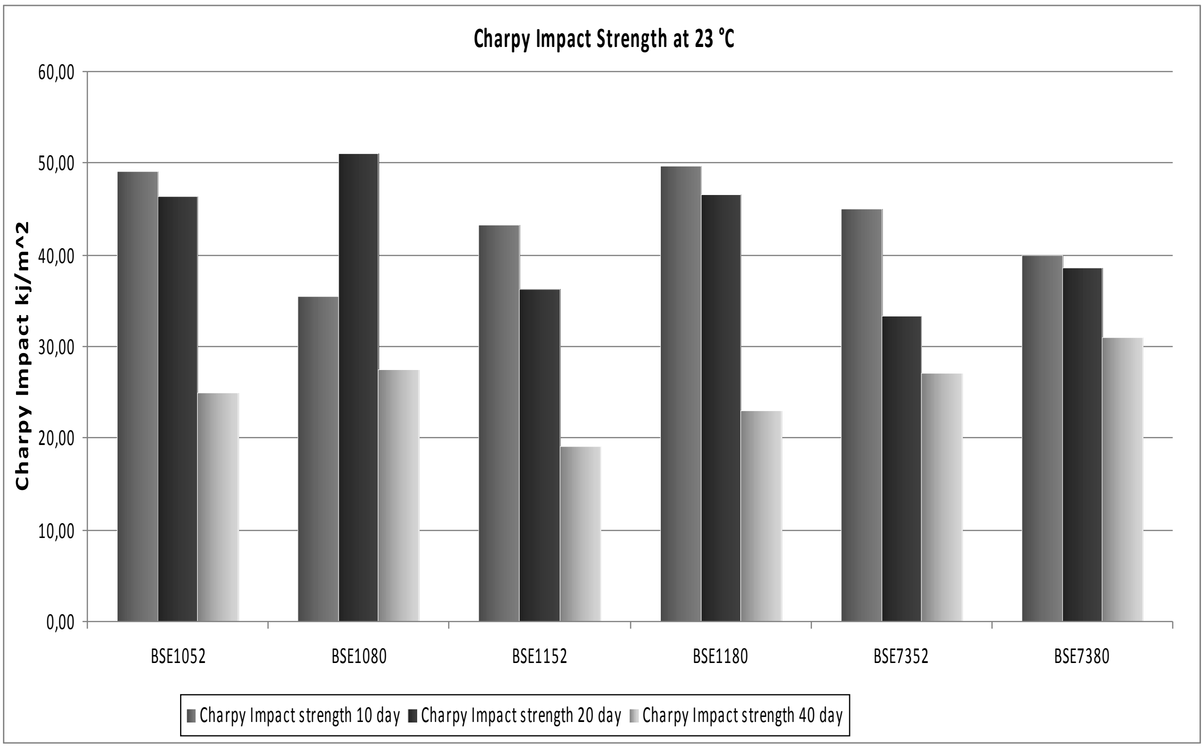


Figure IV.7 Charpy Impact Strength of Low Profile Systems

d) Hardness

Hardness was tested according to ASTM –D 2583 by barcol apparatus. Barcol Hardness is used to determine the hardness of both reinforced and non-reinforced rigid plastics. The specimen is placed under the indentor of the Barcol hardness tester and a uniform pressure is applied to the specimen until the dial indication reaches a maximum. The depth of the penetration is converted into absolute Barcol numbers. Specimens are required to be a minimum thickness of 1.5 mm.

Table IV.15 Hardness of Low Profile Systems

HARDNESS	BARCOL	**BSE 1052**	**BSE 1080**	**BSE 1152**	**BSE 1180**	**BSE 7352**	**BSE 7380**
	AVERAGE	69.4	69.2	57.3	60.7	58.4	69.4

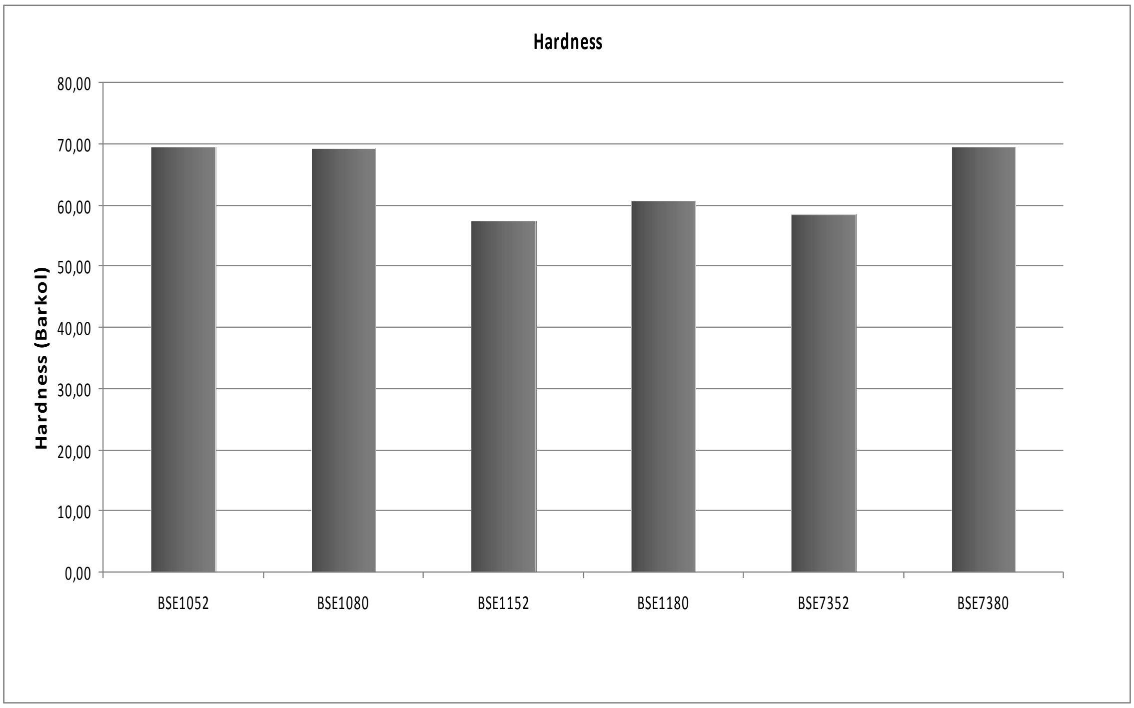


Figure IV.8 Hardness of Low Profile Systems

e) Water Absorption

Water Absorption was tested according to ISO 62: 2008 at 23 and 100 °C temperatures. ISO 62:2008 describes procedures for determining the amount of water absorbed by plastic specimens of defined dimensions, when immersed in water or when subjected to humid air under controlled conditions [80]. Samples were kept 24 hours to get condition in 23 °C in stove. Thereafter samples were kept 24 hours in 23 °C in water. In order to determine the water absorption degrees at 100 °C, the sample were kept 0.5 hours at 100 °C in water.

Table IV.16 Water Absorption of Low Profile Systems

%	**BSE 1052**	**BSE 1080**	**BSE 1152**	**BSE 1180**	**BSE 7352**	**BSE 7380**
water absorption at 23 °C	0.04	0.12	0.15	0.22	0.27	0.19
water absorption at 100 °C	0.15	0.11	0.18	0.22	0.25	0.21

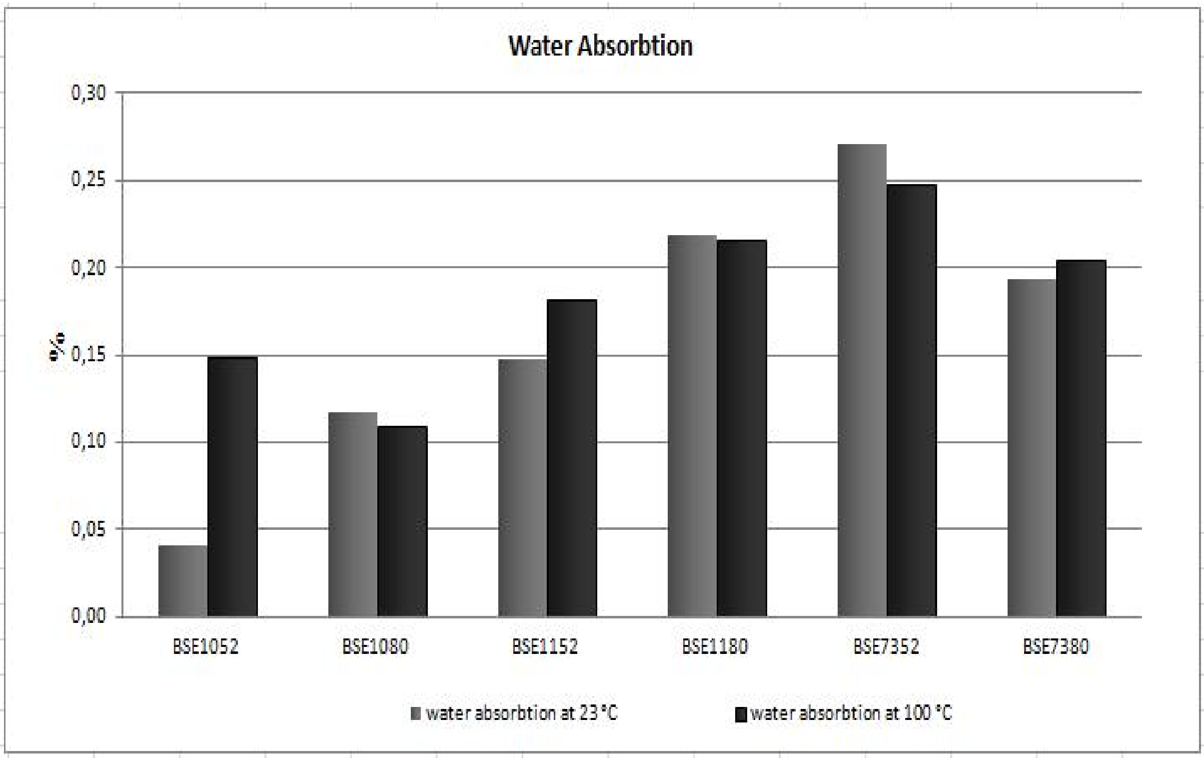


Figure IV.9 Water Absorption of Low Profile Systems

f) <u>Shrinkage in Mold</u>

For all the prepared plates shrinkage in mold were tested according to TSE 2351 EN 1842 [81]. Plates were kept 24 hours at 23 °C in stove to gain conditions. Thereafter plates were measured by calipers.

Table IV.17 Shrinkage in Mold of Low Profile Systems

Shrinkage (%)	BSE 1052	BSE 1080	BSE 1152	BSE 1180	BSE 7352	BSE 7380
	-0.04	-0.01	-0.11	0.02	-0.09	-0.04

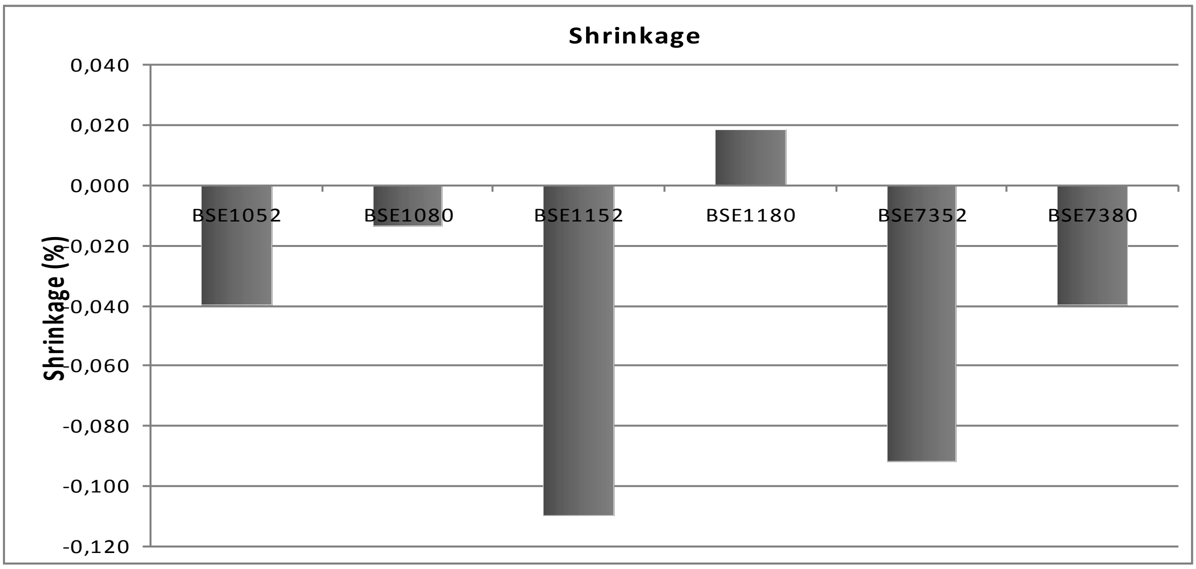


Figure IV.10 Shrinkage in Mold of Low Profile Systems

g) <u>Density</u>

Density was measured according to ISO 1183 test standards [82]. There are two basic test procedures, Method A and Method B. The more common being Method A, can be used with sheet, rod, tube and molded articles. For Method A, the specimen is weighted in air then weighed when immersed in distilled water at 23°C using a sinker and wire to hold the specimen completely submerged as required. Procedures, Method A and Method B. Density and Specific Gravity are calculated [83].

Table IV.18 Density of Low Profile Systems

Density (g/cm^3)	**BSE 1052**	**BSE 1080**	**BSE 1152**	**BSE 1180**	**BSE 7352**	**BSE 7380**
	1.63	1.61	1.63	1.64	1.61	1.62

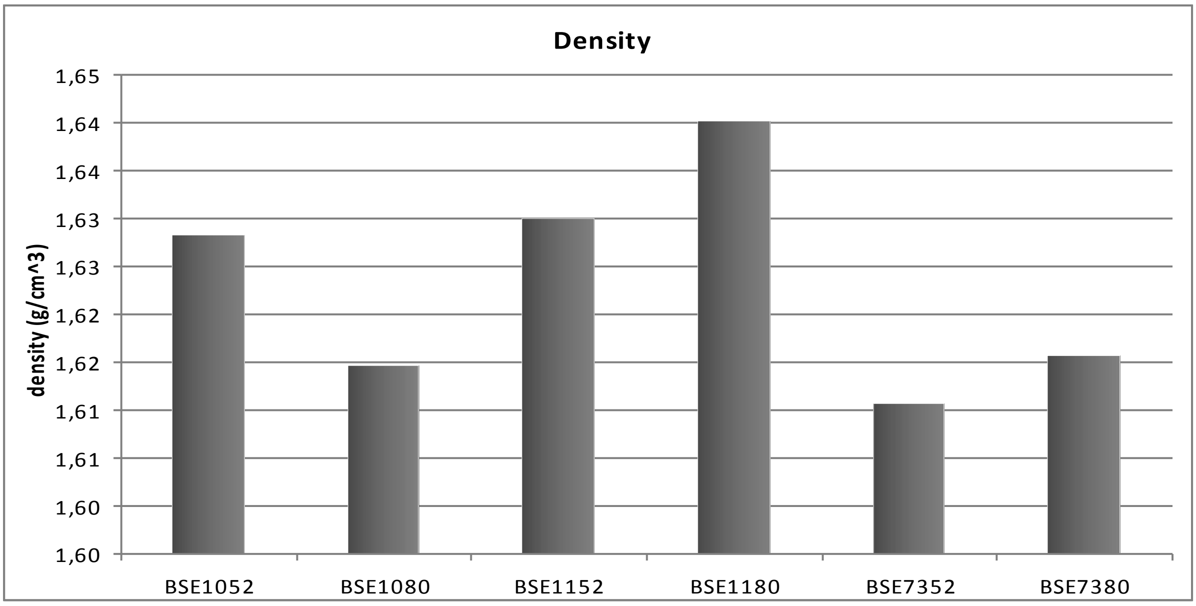


Figure IV.11 Density of Low Profile Systems

h) <u>Surface Resistivity</u>

Surface resistivity was tested according to IEC 60093 standards by METRISO C device [84]. The test method is used to determine volume and surface resistivity. Results are reported in ohms.

Table IV.19 Surface Resistivity of Low Profile Systems

	VOLTAGE	**BSE 1052**	**BSE 1080**	**BSE 1152**	**BSE 1180**	**BSE 7352**	**BSE 7380**
Surface Resistivity (GΩ)	**100 V**	100	100	100	100	100	100
	250 V	100	100	100	100	100	100
	500 V	100	100	100	100	100	100
	1000 V	100	100	100	100	100	100

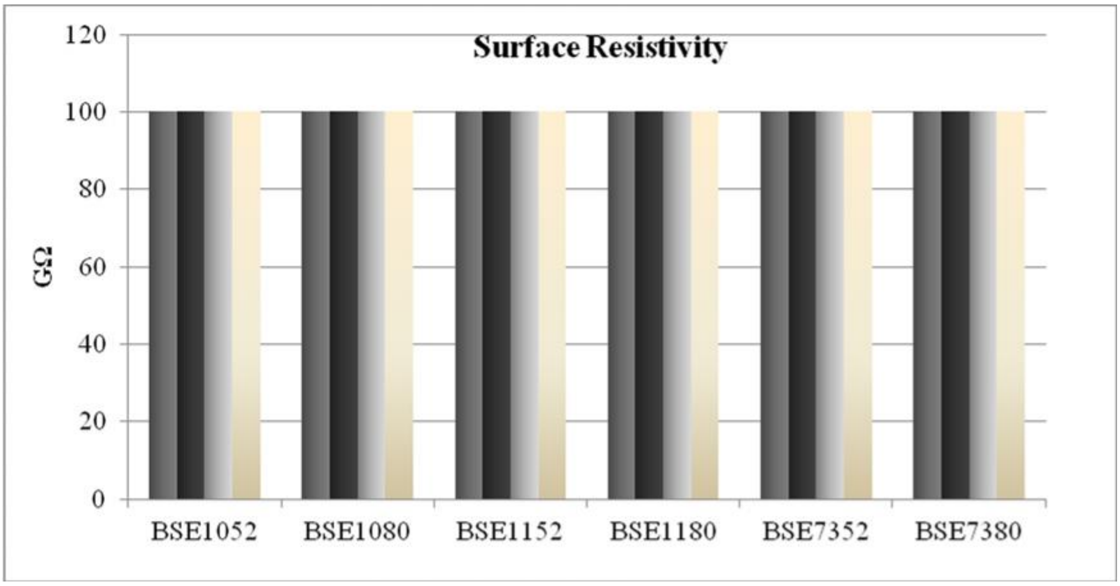


Figure IV.12 Surface Resistivity of Low Profile Systems

i) Glow Wire Testing

Glow wire behaviors were tested according to IEC 60950 test standards [63]. Plates were cut 150 x 150 x 4 mm dimensions. Glow wire at 850 °C was touched on the surface of plates for a period of 30 sec. Dropping or flowing was observed from the surface of plates. There were not neither dropping nor flowing from the surface of the plates. The diameter of burning was measured.

Table IV.20 Glow Wire Testing of Low Profiles Systems

Glowing Wire Test	**BSE 1052**	**BSE 1080**	**BSE 1152**	**BSE 1180**	**BSE 7352**	**BSE 7380**
Diameter of burning (mm)	4.96	2.46	3.78	3.79	3.67	3.84

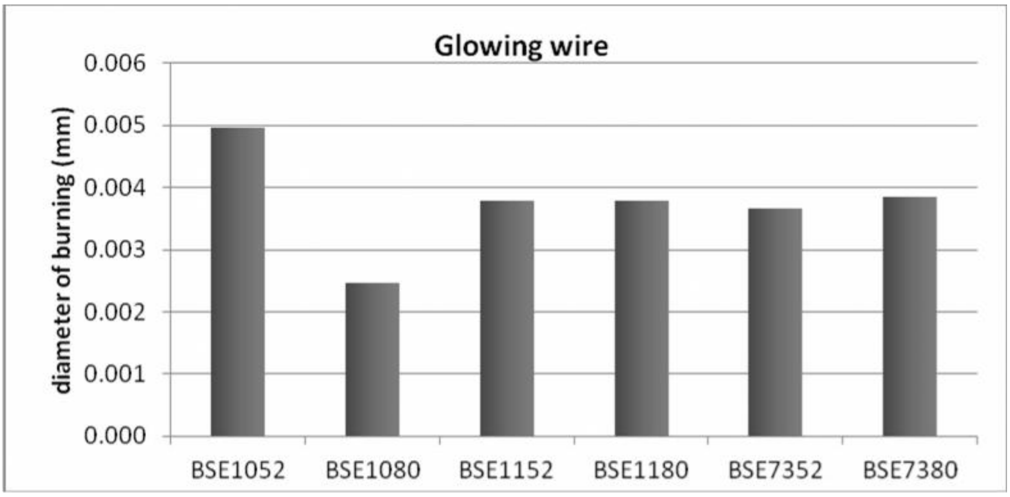


Figure IV.13 Glow Wire Test of Low Profile Systems

The results of low profile systems showed that DSM Palapreg H1080-01 supported high mechanical properties than DSM Palapreg H852-03.

After this stage, DSM Dewilux 511.950 as unsaturated polyester, DSM Atlac XP 810 as vinyl ester, Epoxy resin system 2 (Araldite XU 3508 / Aradur 1571 / Accelerator 1573 / Hardener XB 3403) and DSM Palapreg H 1080-01 were chosen to manufacture high mechanical compounds.

IV.4 MANUFACTURING HIGH MECHANICAL COMPOUNDS

High mechanical compounds (HMC) were manufactured at SAMİ TONGÜN CO. The formulation presented in Table IV.21 was used to produce the required compound composite.

Table IV.21 The formulation chart

Materials	**%**
Resin	30
LP Additive (H852/H 1080)	9.2
Peroxide	0.6
Inhibitor	0.02
Filler	10.6
Glass fiber	50.4
Total	100

Epoxy resin system 2 was arranged according to resin ratio in mixing system 2.

Table IV.22 The Mixing Ratio of Epoxy resin system 2

Components, parts by weight	Ratio 2
Resin XU 3508	100
Aradur 1571	23
Accelerator 1573	5
Hardner XB 3403	12

Unsaturated polyester resin, vinyl ester resin and epoxy resin paste were prepared respectively by using dissolver with 2 tones mixing capacities. Materials were added according to formulation chart given in Table IV.21.

Sheet molding compound machine was prepared as 100 roving wick (CAMELYAF ROVING SMC 3 2400 text) and 450 g/m^2 (CAMELYAF MAT8) were used as reinforcement. Glass fibers were put in machine guides (Figure IV.14). Doctor blade spare of SMC machine was arranged as 1 mm. The doctor blade width of SMC machine was arranged as 850 mm. Conveyor speed of SMC machine was arranged as 5 rpm. Carrier films were chosen as PA/PE film that thickness of film was 22 µm.

Figure IV.14 Glass Fibers were guided in SMC machine.

Each of resin paste were manufactured using sheet molding compound processes with special methods reinforced glass fibers. Glass Fibers were not cut as in SMC processing. Each Roving and MAT8 glass fibers were used together. Obtained high mechanical compounds were matured at matured room at 26 °C.

Figure IV.15 The Processing of HMC

Determination Hot Pres Molding Parameters

Hot pres molding parameters were investigated using reactivity machine. The Reactivity machine was produced by SAMİ TONGÜN CO. It is used to determine pres parameters. The heat condition of reactivity pres was arranged as 150 °C for the manufacturing step. The graphs were listed in Figures IV.16 and the rest of the figures are given in the CD.

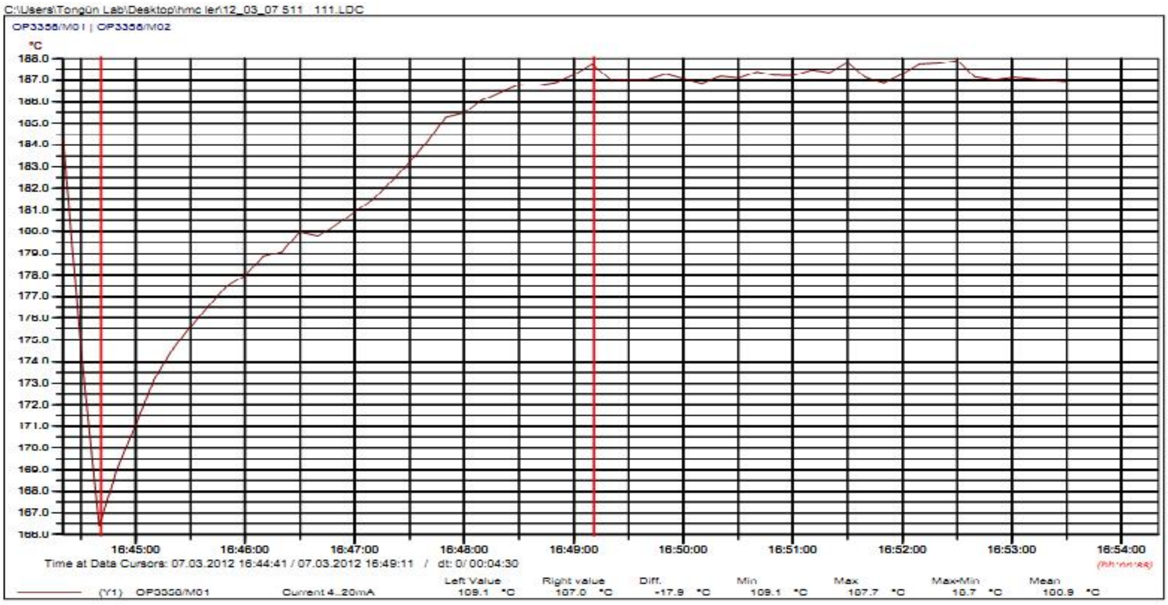


Figure IV.16 The Curing and Max temp. for UP-HMC

The cure times and maximum temperature were specified in Table IV. 23. As expected, VE had the fastest cure time and lowest peak temperature and epoxy system 2 gave the slowest curing time having highest peak temperature. From these results working conditions of the control plates and shields were determined, where 100 bar pressure was used in press. The heat of bottom molds and the upper molds were set as 140 °C and 145 °C, respectively.

Table IV.23 Cure times and max. temperatures of HMC's

HMC	Cure times (min:sec)	Max. Temperature (°C)
UP	04:30	187.7
VE	03:10	182.7
EPOXY	06:29	190.9

<u>Preparing to Hot Pres Molding</u>

HMC of control plates for each resins were prepared and pressed to investigate the mechanical properties that were flexural, tensile and impact strength, and others. The produced HMC were cut in 200x200 dimensions for 4 plies. The plates were arranged quasi isotropic lay up that had been mentioned in Section II.3.2.3. The quasi-isotropic lay-up laminated composites that can be seen in Figure IV.17 have found out to gained more mechanical properties and ballistic resistances.

HMC of shields panels for each resins were prepared and pressed to investigate ballistic characterization. With the same control panels, HMC’s were cut in 250x350 mm as 16 plies as quasi isotropic for obtained one shields.

Figure IV.17 Quasi–isotropic lay-up

The hot pres molding pressure was adjusted 100 bars, and bottom mold 140 °C, upper mold 145 °C were adjusted to pres HMC’s for each control and shield panels. The molding times were adjusted 20 minutes for 20 ± 2 mm thickness. Shield panels were pressed the hot pres molding as shown Figure III.16.

IV.4.1 Mechanical Properties of Control Plates

Mechanical properties were investigated for produced quasi isotropic control plates. Mechanical properties that include flexural, tensile and impact strength and modulus, surface resistivity and flame behaviors, were tested by using TS EN ISO standardizations for fiber reinforcement plastics as determining of low profile additives in the previous section.

a) Flexural Strength and Modulus
b) Tensile Strength and Modulus
c) Charpy Impact Strength
d) Flame Behavior
e) Density

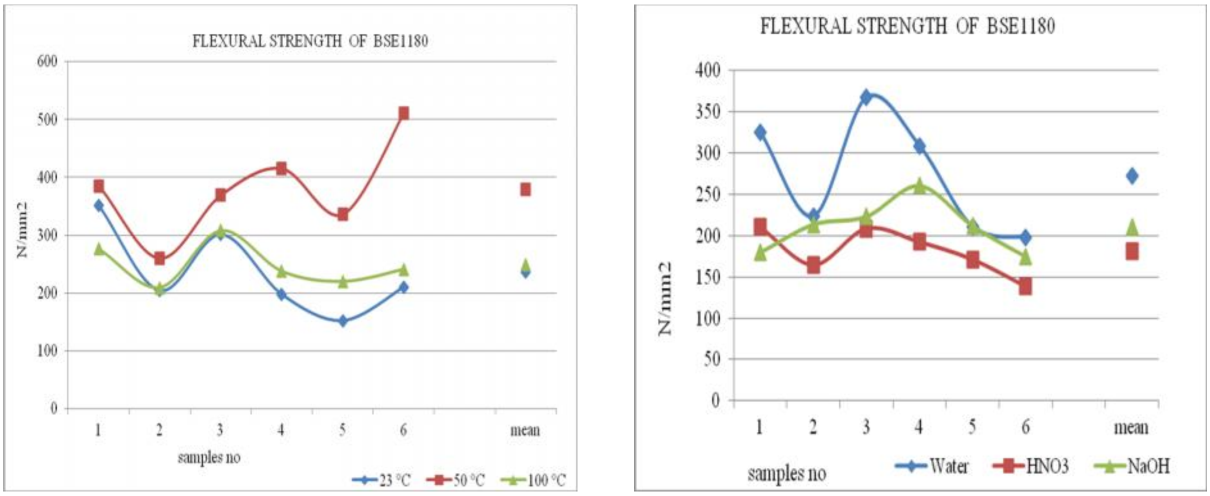
A) Flexural Strength and Modulus

Flexural strength and modulus were investigated in different heat conditions and chemical solutions. All the data acquired during the experiments are given in Table IV.24. Flexural strength and modulus helps to understand behavior of materials at different conditions under loading.

Table IV.24 The Flexural Strength of BS1180

BSE 1180	Max Force Fmax	Max Deformation Force	Max Strength Force	E- modul
Unit	N	mm	N/mm^2	N/mm^2
Conditions				
23 °C	291.7	10.3	236	4505
50 °C	230.3	9.5	379	14257
100 °C	140.3	7.3	248.7	14039
WATER	299.7	9.8	272.2	4385
HNO_3	224	6.9	181.1	3614
NaOH	260.3	7.7	210.4	4256

As seen in Table IV.24, the highest flexural strength was evaluated at 50 ^oC. This result was unexpected. However, the behavior of deformation force was different than strength force, since it was decreased with the increasing temperature. Another interesting result was seen in e-module results where it also made a peak at 50 ^oC. This result was continued in the other various composite control plates. In Figure IV.18, the evaluated results for BSE 1180 for the flexural strength are shown for easier readability.



a b

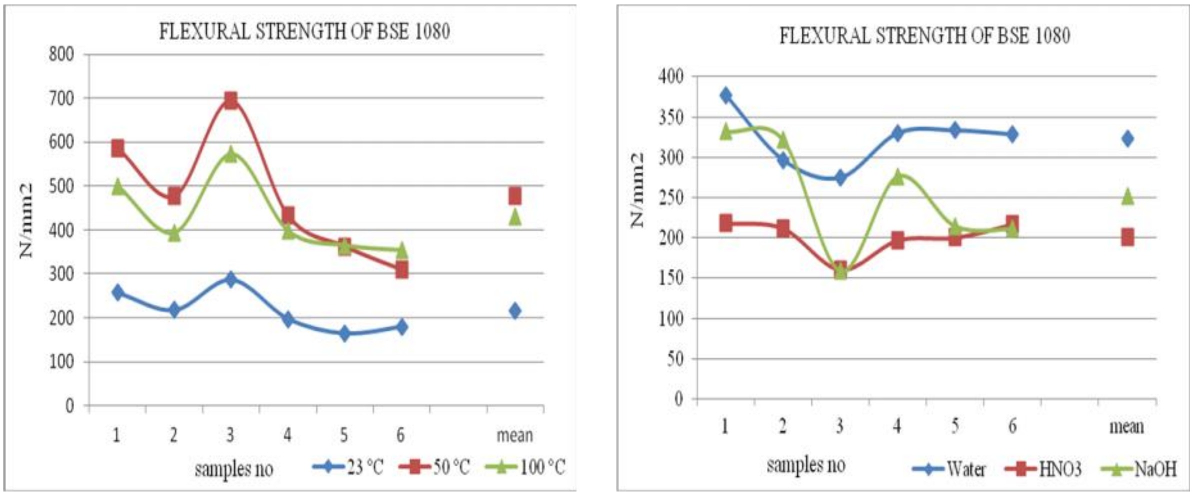
Figure IV.18 Flexural strength of BSE1180; a: varying temp., b: varying environment

In Table IV.25, the mechanical properties of BSE 1080 are listed for 23, 50 and 100 °C and in water, HNO_3, and NaOH. As expected, the e-modul of BSE1080 was increased with the increasing temperature BSE 1080.

Table IV.25 The flexural strength of BSE 1080

BSE 1080	Max Force Fmax	Max Deformation Force	Max Strength Force	E- modul
UNIT Conditions	N	Mm	N/mm^2	N/mm^2
23 °C	275.3	10.7	216,9	3246
50 °C	273.7	11.7	476.9	1544
100 °C	234	11.1	430.4	16229
WATER	384	10.6	323.3	4013
HNO_3	244.7	7.6	200.9	3647
NaOH	263.2	12.4	257.6	4738

The same interesting behavior for flexural strength was observed for BSE 1080 having highest max. strength force. In figure IV.19, the flexural strength variation for different conditions are specified. As seen clearly the max. strength force was again evaluated at 50 °C. Also, it can be concluded from Figure IV.19 that it is less durable under strong acidic conditions.



a **b**

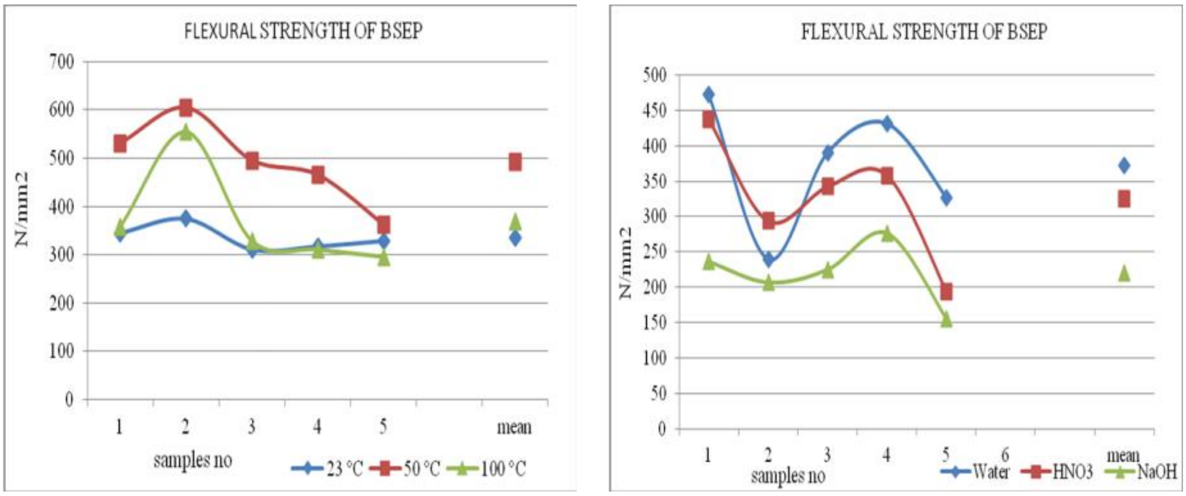
Figure IV.19 The flexural strength of BSE 1080; a: varying temp., b: varying environment

The mechanical experiments conducted for BSEP are given in Table IV.26. Also, the same unexpected behavior was again observed for the max. strength force at 50 °C. E-modul change was same as BSE1080.

Table IV.26 The flexural Strength of BSEP

BSEP	Max Force Fmax	Max Deformation Force	Max Strength Force	E- modul
UNIT / Conditions	N	mm	N/mm^2	N/mm^2
23 °C	526.4	11.7	335.2	4323
50 °C	361.2	10	491.5	15051
100 °C	247.6	9.4	369.5	15877
WATER	471.2	9.6	372.1	4573
HNO_3	402.8	11.1	325	4163
NaOH	197.6	14.4	220.3	2468

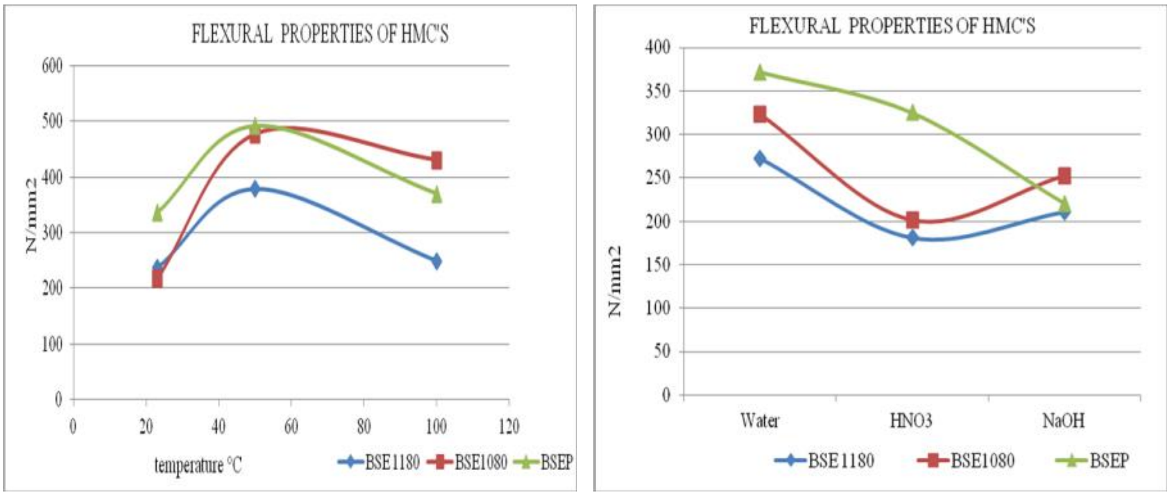
The flexural strength of BSEP for various conditions are shown for readability purposes in Figure IV.20. It is clearly seen from the figure that the strength evaluated at 50°C is way higher.



a b

Figure IV.20 The Flexural Strength of BSEP; a: varying temp., b: varying environment

As seen in Figures IV. 18-21, the highest flexural strength was observed at 50 °C for all the composites under investigation. Another interesting result was monitored from the results of all the composites conducted inside water, where max. flexural strength was evaluated.



a **b**

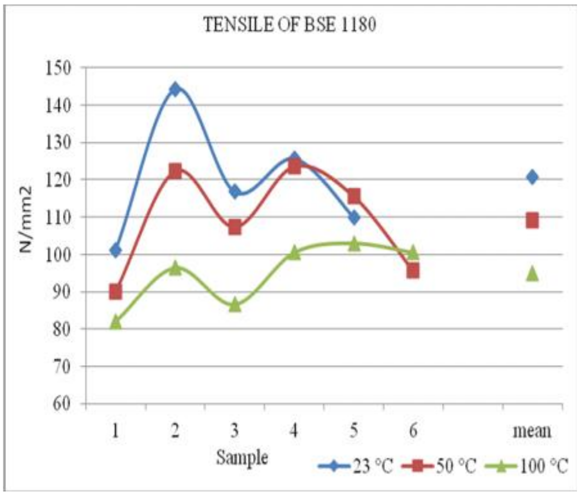
Figure IV.21 The Flexural Sterngth of overall evulation of HMC's; a: varying temp., b: varying environment

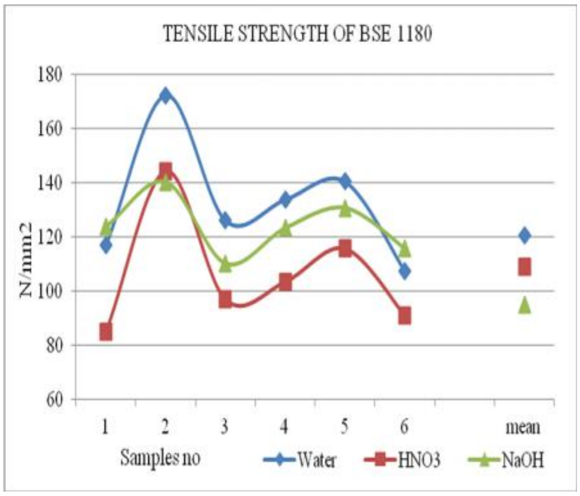
B) TENSILE STRENGTH

The tensile strength of BSE1180, BSE 1080, and BSEP are presented in Tables IV.27-29, respectively. As expected from the quasi-isotropic structures of the materials used in the study, the max. tensile strength were observed at 23 °C for all the composites. Due to the same reason, e-moduls of all the composites were evaluated as the maximum in water solution. The summary of the tensile strength for the three composites are shown in Figures IV.22-25.

Table IV.27 Tensile Strength of BSE 1180

BSE 1180	Max Force Fmax	Max Deformation Force	Max Strength Force	E- Modulus
UNIT	N	mm	N/mm^2	N
Conditions	5067	3.8	120.8	8117
23 °C	4474	3.6	109.1	7518
50 °C	3949	3.5	94.9	7930
100 °C	5257	3.7	133	10019
WATER	4130	3.2	106.1	8022
HNO_3	4678	3.6	124	9070



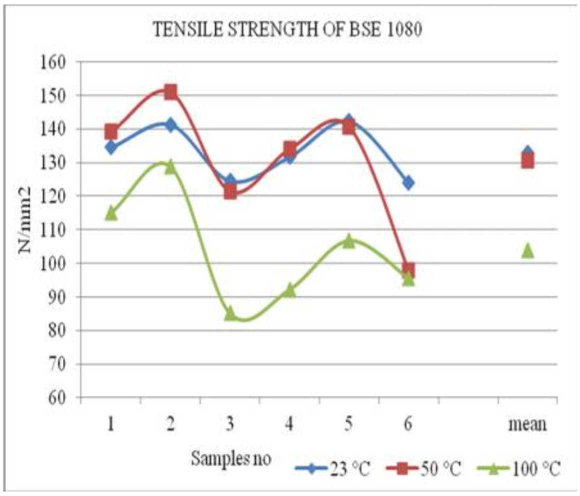


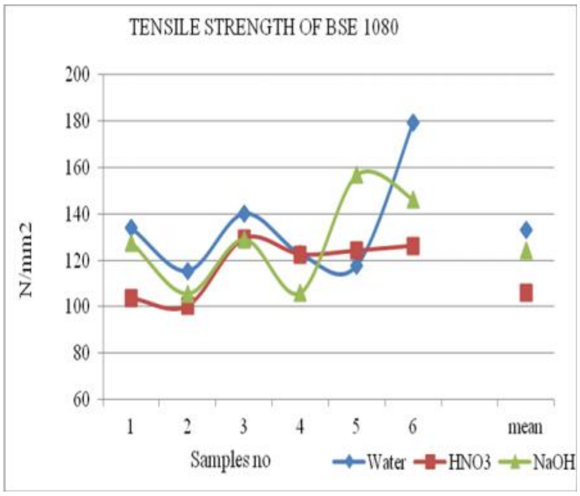
a **b**

Figure IV.22 Tensile Strength of BSE 11804; a: varying temp., b: varying environment

Table IV.28 Tensile Strength and modulus of BSE 1080

BSE 1080	Max Force Fmax	Max Deformation Force	Max Strength Force	E-Modulus
UNIT	N	mm	N/mm2	N
Conditions	5364	4.1	133	6739
23 °C	5336	3.8	130.7	9640
50 °C	4185	3.6	104	6793
100 °C	5257	3.7	133	10019
WATER	4130	3.2	106.1	8021
HNO_3	4678	3.6	124	9070





a **b**

Figure IV.23 Tensile Strength of BSE 1080 a: varying temp., b: varying environment

Table IV.29 Tensile Strength of BSEP

BSEP	Max Force Fmax	Max Deformation Force	Max Strength Force	E- Modulus
UNIT	N	mm	N/mm2	N
Conditions	7566	4.8	175.2	8258
23 °C	6623	4.	146.5	9352
50 °C	5419	4.5	147.4	9885
100 °C	6410	4.2	157	11710
WATER	5696	3.8	133.4	9789
HNO_3	5559	4.9	153.2	10387

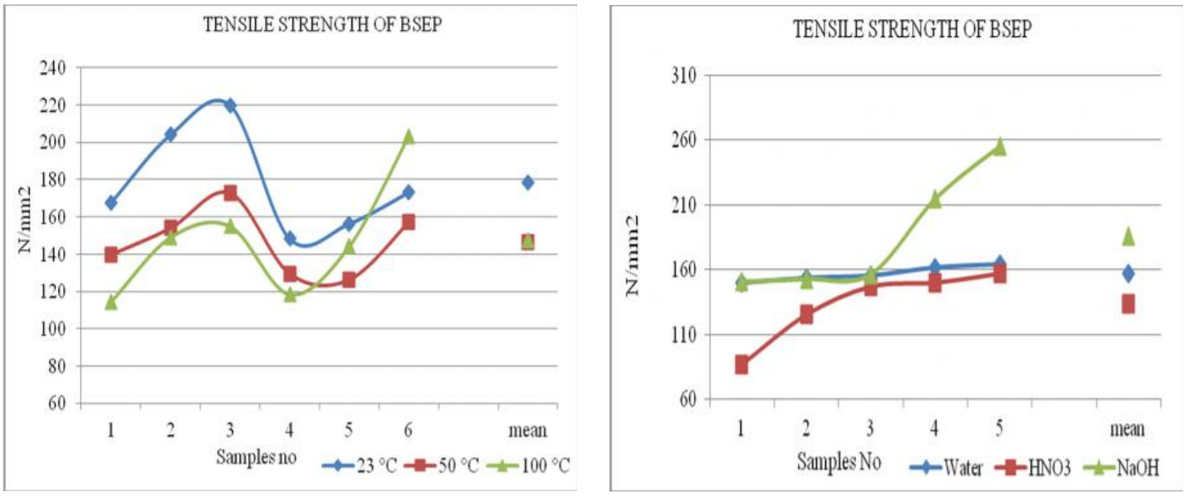


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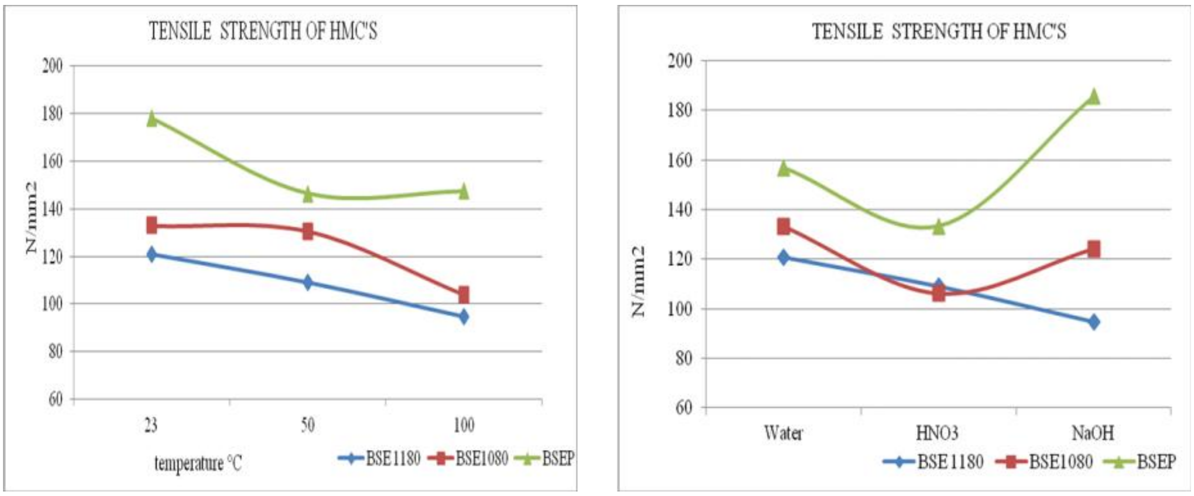
Figure IV.24 Tensile Strength of BSEP; a: varying temp., b: varying environment



a b

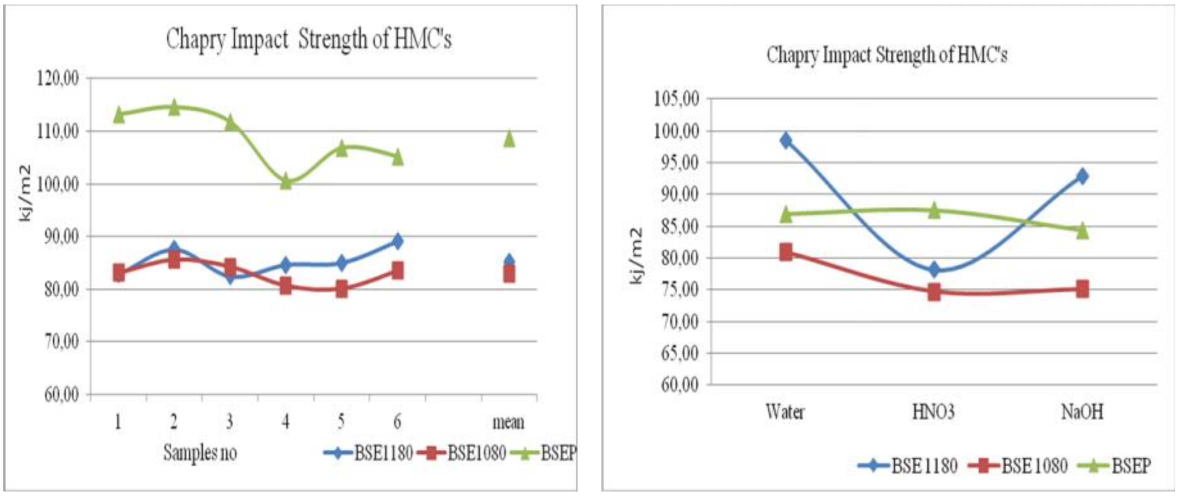
Figure IV.25 Tensile Strength of overall evulation of HMC’s; a: varying temp., b: varying environment

C) Charpy Impact Strength

Table IV.30 presented charpy impact strength of all the composites for different conditions. BSEP showed the best results from BSE1080 and BSE 1180. As clearly seen in Figure IV.26, the charpy impact results evaluated with water did not showed the same affect. However, the water had an impact in the tensile and flexural strength results.

Table IV.30 Charpy Impact Strength

	BSE 1180	BSE 1080	BSEP
23 °C	85.3	82.9	108.7
WATER	98.5	80.9	99.1
HNO3	78.2	74.7	87.5
NAOH	90.9	75.1	93.2



a **b**

Figure IV.26 Charpy Impact Strength of HMC; a: varying temp., b: varying environment

D) FLAME BEHAVIOR

Flame behavior was investigated according to UL 94 standards [77].

Table IV.31 Flame Behavior of HMC's

BSE 1180		BSE 1080		BSEP	
1. 10SN	2.10 N	1. 10SN	2.10 SN	1.10SN	2.10 SN
0	0	0	0	0	0
0	0	0	0	0	0
0	4	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
V0		V0		V0	

E) <u>DENSITY</u>

Table IV.32 Density of HMC's

	BSE 1180	BSE 1080	BSEP
Density g/cm^3	1.61	1.64	1.60

IV.4.2 Ballistic Characteristic of Shields

Ballistic Characteristic was performed using ballistic equipment as shown in Figure III.27 at Afyonkarahisar 8 Main Maintenances Command. Shields were prepared according to NIJ0108.01 standard. First, ballistic performance was started in level III with 7.62 x 51 mm projectiles having 838 ± 15 m/sn speed from 15 meter. Because of the lack of mechanical properties all the composites have passed (pierced) the 7.62 x 51 mm projectiles. However, the deformations on the composite plates differed. The composite produced from the epoxy system 2 had the minimum deformation.

Then, the level IIIA was selected to proceed for the investigation of ballistic characterization. Ballistic protecting standard of level IIIA uses 9 x 19 mm projectiles having 426 ± 15 m/sn speed from 5 meters.

Results showed (Table IV.33) that BSE 1180, BSE 1080 and BSEP shields protected with level IIIA standard. The shields had shown different collapse behavior. Collapsing of BSE 1180, BSE1080 and BSEP were measured as 15 mm, 18 mm and 12 mm, respectively, as seen in Table IV.33. Collapsing was measured by using paste behind the shields in ballistic performance as seen as front and behind for each ones in Figure IV.27.

Table IV.33 Ballistic Characteristic Test Results

S. No	Material	Projectiles Types	Ballistic Level and Test Conditions	Values		
				Impact Surface	Projectile Speed (m/sn)	Collapsing (mm)
BSE 1180	Thickness:22.5 mm Weight : 2190 kg Dimension: 280x230 cm	7.62 x 51 mm FMJ	Speed:838 ±15 m/sn Distance : 15 m Level III	Front	825	Pierced
		9 x19 mm FMJ	Speed: 426 ±15 m/sn Distance : 5m Level III A		433 440 431 441	15 15 14 16
BSE 1080	Thickness:20mm Weight : 2010 kg Dimension: 280 x230 cm	7.62 x 51 mm FMJ	Speed:838 ±15 m/sn Distance : 15 m Level III	Front	842	Pierced
		9 x19 mm FMJ	Speed: 426 ±15 m/sn Distance : 5m Level III A		427 436 444 432	19 16 14 15
BSEP	Thickness:19.5 mm Weight : 2030 kg Dimension: 280 x230 cm	7.62 x 51 mm FMJ	Speed:838 ±15 m/sn Distance : 15 m Level III	Front	827	Pierced
		9 x19 mm FMJ	Speed: 426 ±15 m/sn Distance : 5m Level III A		436 437 438 426	12 13 12 12

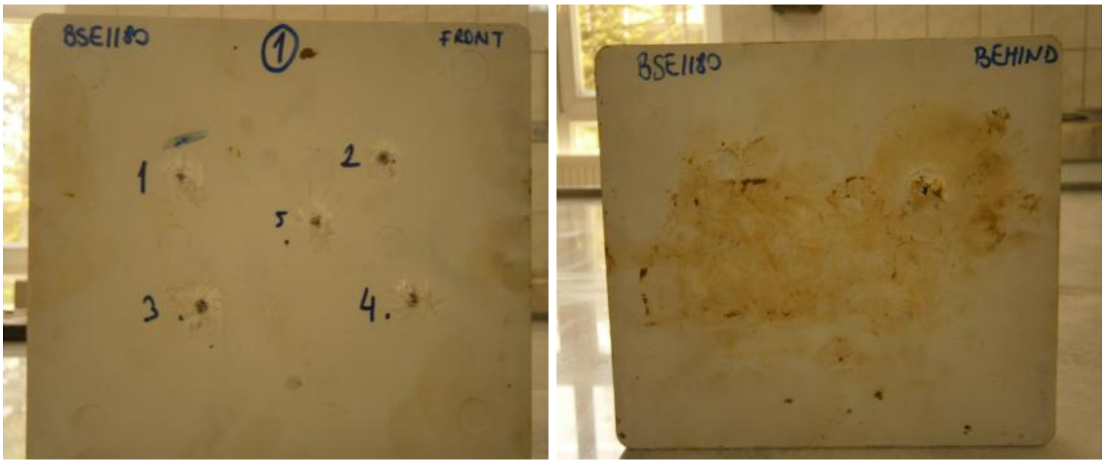


Figure IV.27 a) Ballistic Performances of BSE 1180

Figure IV.27 b) Ballistic Performance of BSE 1080

Figure IV.27 c) Ballistic Performance of BSEP

As seen from the results of the ballistic characterization, BSEP had the best protection due to having less collapse.

CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS

V.1 CONCLUSIONS

The most important goal of this thesis was to produce composites that can be used as shield plates or panels. Thus, properties of the composites were investigated both mechanically and in ballistic. Three different systems were chosen. The results presented in the thesis can be summarized as follows.

1. Production of HMC using epoxy is the first successful implementation especially in massive production.

2. The cure behavior of unsaturated polyester and vinyl ester were found out to be same.

3. DSM PALAPREG 511-950 (UP) and DSM ATLAC XP 810 (VE) had the same exothermic peak and very close cure time.

4. Epoxy system 2 had a longer curing time than epoxy system 1, but had a lower exothermic peak.

5. The formula developed for epoxy system 2 gained the ability to separate from the protector film.

6. Again, the results showed that epoxy system had higher flexural, tensile, and charpy impact strengths.

7. DSM Palapreg H1080-01 as polyvinyl acetate was chosen to be the most effective low profile additive.

8.DSM Dewilux 511.950 as unsaturated polyester, DSM Atlac XP 810 as vinyl ester, Epoxy resin system 2 (Araldite XU 3508 / Aradur 1571 / Accelerator 1573 / Hardener XB 3403) and DSM Palapreg H 1080-01 were chosen to manufacture high mechanical compounds.

9. HMC Vinyl ester was found out to have the fastest curing time, where epoxy system HMC had the slowest curing time.

10. All the prepared HMC had almost the same exothermic peaks.

11. The flexural strength experiments conducted for three different temperatures, where it was found to have the max. flexural strength at 50 ^{o}C for all the composites.

12. The flexural strength experiments conducted for three different solution environments, it was found to have the max. flexural strength in water for all the composites.

13. All the composites prepared from UP, VE, EP in this study, which were under investigation, has been proved to have bulletproof property of Level III-A.

14. BSEP showed the less collapse in ballistic test.

V.II RECOMMENDATION

1. Composites produced from ceramics can be further investigated since the material is very widely used in different fields and is an industrial product.

2. Silicon based composite shields can also be further investigated in this protection field. First, preliminary study was undertaken and the result of the ballistic test can be seen in the CD.

3. Different kinds of fibers can be added to change the mechanical strength of the composites that were produced to have a bulletproof property of Level III. S glass, carbon fiber and aramid can be chosen.

4. The kinetics of the polymerization process realized under hot press may be modeled in order to have a primary idea of how the mechanical properties would be affected along with the chemical properties.

5. The dimensions and the weight of the composite shields can be reduced and retested.

6. The water behavior for these systems can be further high-lightened.

REFERANCES

[1] Kindo S, “Study of mechanical behavior of coir fiber reinforced polymer matrix”, Roll no:10603053, Dep.of Mech.Eng. National Institue of Technology , Rourkela 769008, **May 2010**.

[2] Kocagıl C, “Polimerik Kompozitlerin Ülkemizdeki ve Dünyadaki Önemi, İç Ve Dış Pazardaki Yeri ve Değerlendirilmesi”, *Uluslar arası Katılımlı Polimerik Kompozitler Sempozyum, Sergi Ve Çalıştayları, 161-162,* **(2008)**.

[3] Barkoula N.M., Peijs T., Mary Q.; "Processing of Single Polymer Composites Using the Concept of Constrained Fibers" *Polymer Composites*, 26, **(2005)** *114-120.*

[4] Douša Q, Koňák Č., Fidler V. and Dušek K., “Cure monitoring of epoxy resins by fluorescence quenching” *Polymer Bulletin 22, 5-6* **(1989)** 585-592.

[5] Barton J.M., Hamerton Ian, Howlin B.J., John R. Jones and Shuyuan Liu, “The development of controllable metal-chelate curing agents with improved storage stability,” *Polymer Bulletin 33*, *3*, **(1994)** 347-353.

[6] Friedrich K., Lu Z. and Hager A. M. “Recent advances in polymer composites’ tribology”, *Wear*, 190, **(1995)** 139-144.

[7] Kaw A. K. "Mechanics of Composite Materials", **(2006)** *CRC Press.*

[8] Önder S. F, "Otomotiv Sanayiinde Kompozit Malzeme Kullanımı", *Mühendis ve Makine,* 39, **(2000)**.

[8] http://www.compositesworld.com/articles/compression-molding-with-structural-carbon-smc.

[9] Gama et al. 2001, Tanoğlu et al. 2001, Vaidya et al. 2001, Bernetich et al. 1998, Mahdi et al. 2000, Tanoglu et al. 2002.

[10] Campbell F.C, Structural composite materials, **2010**, *ASM international.*

[11] http://www.obitet.gazi.edu.tr/obitet/malzeme_bilgisi/kompozit%20malzemeler.pdf

[12] Naik N.K, Shrirao P., B.C.K “Redballistic impact behavior of woven fabric composites formulation” *International Journal of Impact Engineering* 32 **(2006)** 1521-1552).

[13] Metin M. “E-Camı/Epoksi Tabakalı Kompozitlerde Düşük Hızlı Darbe Hasarının Burkulma Özelliklerine Etkisi” , Selçuk Üni. Fen bilimleri Enst. Makine Mühendisliği Anabilim dalı Y.Lisans Tezi, **2008.**

[14] Demircioğlu G. “Effect Of Fıber Length On Short Glass Fıber Reınforced Epoxy Composıte Materıals”, Gazi Unıversıty Instıtute Of Scıence And Technology , **June 2006.**

[15] www.phantomplastics.com/attachments/File/Introduction_to_Filled_Thermoplastics.pdf,

Chris DeArmitt 2009,FILLED THERMOPLASTICS ,

[16] http://www.primethermosets.com/introtothermosets.pdf, an introduction thermoset to thermosets, R. Bruce, Prime IBM (retired) /cosultant.

[17] http://www.plasticseurope.org/Documents/Document/20100308130622 PIRA_UPES_Cefic_Feb2004-20040923-ALL-007-EN-v1.pdf, MIGRATION OF STYRENE FROM UNSATURATED POLYESTER RESINS.

[18] http://www.acmanet.org/resources/07papers/powell112.pdf, COMPOSITES & POLYCON 2007 American Composites Manufacturers Association October 17-19, **2007** ,Tampa, FL USA Reactive Copromoter for Unsaturated Polyester Resins by ,Jeffery E. Powell and Angela H. Honeycutt Eastman Chemical Company P.O. Box 1974, Kingsport TN 37662-5230.

[19] Yılmaz G.Y.,"Cam Elyaf Katkılı Doymamış Polyester Malzemelerde Mineral Katkıların Mekanik Ve Tribolojik Özellikleri", Yüksek Lisans Tezi, Mayıs 2006, Sakarya Üniversitesi.

[20] Kosar, V. and Z. Gomzi. "In depth analysis of the mathematical model of polyester thermoset curing" *European Polymer Journal* **(2004)** 40:2793-2802.

[21] Tugrul A., Seyhan T, "Development Of Multı And Double Walled Carbon Nanotubes (Cnts)/Vınylester Nanocomposıtes, A Thesis Submitted to the Graduate School of Engineering and Sciences of İzmir Institute of Technology in Partial Fulfillment of the Requirements for the Degree of, Doctor Of Phılosophy, in Mechanical Engineering, ,**Agust 2008**, İzmir.

[22] Dua, S., R.L. Mc Cullough, and G.R. Palmase, "Copolymerization kinetics of styrene/vinyl-ester systems: Low temperature reactions" *Polymer Composites* **(1999)** 20:379-389.

[23] B. Ellis, Chemistry and technology of Epoxy Resins, Blackie Academic&Professional, p. 1- 4.44, 1993.

[24] Yılmaz K. "Dynamic Mechanical Characterizations Of Carbon Fıber - Polyurethane And Epoxy Composıtes" B.Sc., İstanbul Technıcal Unıversıty Instıtute Of Scıence And Technology, janurary **2008.**

[25] Sue H-J, Puckett PM, Bertram JL, Walker LL, "The network structure of epoxy systems and its relationship to toughness and toughenability. In: Pearson, Sue, Yee, editors. Toughening of plastics: Advances in modelling and experiments" *ACS Symposium Series* **2000**. p. 759.

[26] Maity, T., Samanta, BC., Dalai, S. and Banthia, AK.. "Curing study of epoxy resin by

new aromatic amine functional curing agents along with mechanical and thermal , evaluation";; *Materials Science and Engineering* A, 464, 38–46. **2007.**

[27] Potter, W.G. Epoxide Resins, Springer-Verlag, New York., **1970**

[28] Lee, H. and Neville, K., 1976. Handbook of Epoxy Resin, McGraw-Hill Book Co.,New York.

[29] Wetzel, B., Rosso,P., Haupert, F. and Friedrich, K., "Epoxy nanocomposites–fracture and toughening mechanisms", *Engineering Fracture Mechanics*", **2006**.,73, 2375–2398.

[30] Zhou, Y., Pervin, F., Rangari, V.K. and Jeelani, S., "Fabrication and evaluation of carbon nano fiber filled carbon/epoxy composite",*Materials Science and Engineering* A, 426, 221–228, **2006**.

[31] Donnet, J.B., "Nano and microcomposites of polymers elastomers and their reinforcement" *Composite Science Technology.,* **2003**., 63, 1085–1088.

[32] BAŞBUDAK M. Plasitk yardımcı maddeleri, ISBN 978-9944-5583-3-4, 82,85,86,95,

[33] http://www.epa.gov/ttnchie1/ap42/ch11/final/c11s13.pdf , The information about glassfiber production.

[34] Matthews, F.L. ve Rawlings, R.D., "Composite materials", *Engineering and Science, Chapman & Hall,* UK, **1994**.

[35] Prepreg Technolgy, Hexcel Corporation, March (**2005**).

[36] Temiz, S., "Balistik kumaşlar ve test yöntemleri üzerine bir araştırma", Yüksek Lisans Tezi, Dokuz Eylül Üniversitesi Fen Bilimleri Enstitüsü, İzmir, 1-34 (**2005**).

[37] E.P. Gellert, S.J. Cimpoeru*, R.L. Woodward , "A study of the e!ect of target thickness on the ballistic perforation of glassfibre-reinforced plastic composites", Australia

[38] Tanoglu M., Gellert E.P.,Cimpoeru S, J, Woodward R.L., Seyhan A. T. "Investigating the effects of a polyester preforming binder on the mechanical and ballistic performance of E-glass fiber reinforced polyester composites", *International journal of Adhesion &adhesives* **2002**.

[39] Kia H.G, "Sheet Molding Compounds science and Technology". Hanser Publishers, Munih Vienna, ISBN 3-446-16213-5, pg 1,2, 29,31,35,49,50,51,55

[40] Adrian P., MIHOC B., Manufacturıng Process And Applıcatıons Of Composıte Materials,.

[41] Peel L., Fabıcatıon Process Assıgnment, Brandon Lee Rıce ,Meen 4336 Composıtes, , February 23, **2004**.

[42] Feraboli P.,Keith T. Kedward, "A new composite structure impact performance " *Composıtes Scıence And Technology,* Received 2 June 2005; accepted 27 September

2005, Available online 14 November **2005.**

[43] Tarim N., Findik F, Uzun H. “Ballistic impact performance of composite structure”, *Composite Structure* ,**1998**.

[44] http://www.mdacomposites.org/mda/psgbridge_cb_mfg_process.html, Inernet searching.Composites Basics: Composites Manufacturing,

[45] http://en.wikipedia.org/wiki/Sheet_moulding_compound, The Processing of sheet molding compound.

[46] Desing For success, A Design & Technology Manual for SMC/BMC, European Alliance for SMC/BMC.

[47] http://www.gtpl.co.in/files/3.%20The%20Pultrusion%20Process.pdf

[48] http://www.etamax.com.au/introduction_to_filament_winding.pdf, Introduction to Filament Winding and Cadwınd, Etamax Engineering.

[49] TDS, Palapreg 2273-01, DSM.

[50] TDS, DSM Dewilux 511.950.

[51] TDS, DSM Atlac XP 810.

[52] TDS, Araldite LY 1556 / Aradur 1571 / Accelerator 1573 / Hardener XB 3403.

[53] TDS, Araldite XU 3508 / Aradur 1571 / Accelerator 1573 / Hardener XB 3403.

[54] TDS, Palapreg H852-01,DSM.

[55] TDS, Palapreg 1080-01, DSM.

[56] TDS for Peroxan po.

[57] TDS for CH 80 Al.

[58] TDS for pergaslow pk 40.

[59] The information of Zinc Stearat http://en.wikipedia.org/wiki/Zinc_stearate

[60] http://www.lyondellbasell.com/Products/ByCategory/polymers/process/PolyethylenePowders/ The information of coethylene.

[61] The product information of portflame SG40.

[62]http://www.camelyaf.com/products/detay.aspx?SectionID=E2%2bCd1RSIhZjiOXAzIQ%2fZQ%3d%3d&ContentID=Rmhcm44TWSlGQS2mPj3OXA%3d%3d
The product information of Roving.

[63] Standard of Glow wire test for plastic IEC 60950.

[64] http://www.matweb.com/reference/surface-resistivity.aspx.

[65] The ballistic test equipment figure http://www.ballisticedge.com.au/laboratory.htm

[66] Composıte Materıals Handbook, Department Of Defense Handbook, Volume 3. Polymer Matrıx Composıtes, Materıals Usage, Desıgn, And Analysıs, Mıl-Hdbk-17-3f, 17 June

2002, Superseding MIL-HDBK-17-3E, 23 JANUARY 1997.

[67] TS EN ISO 14125 Fiber Reinforced Plastic composites- Determination of Flexural Properties.

[68] TS EN ISO 527-4 - Determination of Tensile Properties.

[69] http://en.wikipedia.org/wiki/Tensile_testing.

[70] Procedure for Determining the Crack Resistance Behaviour Using the Instrumented Impact Test, W. Grellmann, S. Seidler, W. Hesse.

[71] ISO 179 Plastics – Determination of Charpy impact properties.

[72] http://www.ides.com/property_descriptions/iso179.asp.

[73] The Information about flammability test. http://www.innovative-polymers.com/ul-94-test-standards-for-plastics.

[74] http://www.ides.com/property_descriptions/UL94.asp ,The Information about horizontal Test.

[75] NIJ 0108.04 Ballistic Resistant Protective Materials, U.S. Department Of Justıce National Institute Of Justice.

[76] Naik N.K, ,Shrirao P., "Composite structures under ballistic impact", *Composite Structures* 66 (**2004**) 579–590.

[77] Naik N.K, Doshi A.V., "Ballistic impact behaviour of thick composites: Parametric studies" , *Composite Structures* 82 (**2008**) 447–464.

[78] M. Mamivand, G.H. Liaghat, "A model for ballistic impact on multi-layer fabric targets" *International Journal of Impact Engineering* 37 (**2010**) 806–812.

[79] E. DeLuca,,J. Prifti, W. Betheney, S. C. Chou," Ballıstıc Impact Damage Of S 2-Glass-Reınforced Plastıc Structural Armor", *Composites Science and Technology* 58 (**1998**) 1453±1461.

[80] ISO 62 Plastics — Determination of water absorption.

[81] TSE 2351 EN 1842 - Plastics-Termoset moulding compounds (SMC-BMC) determination of compression moulding shrinkage.

[82] ISO 1183 - Plastics - Methods for determining the density of non-cellular plastics – Part 1: Immersion method, liquid pyknometer method and titration method (ISO 1183-1:2004).

[83] http://www.ptli.com/testlopedia/tests/density-specgrav-d792.asp.

[84] IEC 60093 - Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials

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EDUCATION

- MARMARA UNIVERSITY
  - Institute for Graduate Studies in Pure and Applied Science
    Chemical Engineering *Master's degree* 2009 – 2012
- MARMARA UNIVERSITY
  - Chemical Engineering *Bachelor's degree* 2004– 2008
- TRAKYA UNIVERSITY – LULEBURGAZ MYO
  - Chemistry *Associate degree* 2000 – 2002
- BURSA ÇİMENTO FABRİKASI EML
  - Chemistry 1996 – 1999

THESIS AND PROJECT

- **Antibacterial Hydrogel Synthesis (Bachelor's thesis)**
  - The thesis is based on to make antibacterial hydrogel synthesis. Chitosan is synthesized from organic chitin with radical reactions. The aim of the thesis is to produce antibacterial hydrogel to use different area like as food industry.
- **Production Of Shield Panels With Polymer Composites And Investigation Of Mechanical Properties (Master's thesis/almost done)**
  - The Master thesis aim of is to produce shield with different polymeric materials like as unsaturated polyester, vinyl ester and epoxy resin, by using sheet molding compound manufacturing
- **Tubitak KOSGEB Project (R&D Engineer/done)**
  - The project aim of is manufacturing pedestrians ways for disabilities people on the roads. Scope of project is to manufacture chemical, physical and mechanical resistance plates by using bor minerals. The Project was closed down in 2009 years with success and the product has patent.
- **KOSGEB Project (Project Manager 10/2011)**
  - The project aim of is to establish new automation system for manufacturing.
- **Tübitak Project (Project Manager 10/2011)**
  - The project aim of is to manufacture Turkey's local and non flammable high voltage boxes. The scope of project is based on researching and developing raw materials.

WORK EXPERIENCE

- SAMİ TONGÜN POLYMERIC GOODS WITH GLASS FIBER A.S
  - **Manufacture Engineer** (10/10/2008 – still)
    - Planning Manufacture for Inside or Outside Customer
    - Producing Qualify Bulk and Sheet Molding compounds
    - Ensuring Intake Necessity Raw Materials
  - **Research and Development Engineer**
    - Exploring new materials to use inside of raw materials
    - Investigating and developing specialty of matters
    - Produce qualify, cheap and strength raw materials
    - Developing raw materials for customers
  - **Quality Control Engineer**
    - Ensuring quality of raw and end of products according to ISO
    - Analyzing sample materials according to ISO
    - Calibrating some technic measurement equipment

- BURSA ÇİMENTO FABRİKASI A.Ş
  - **Production – Engineering Trainee** (07 - 09/ 2007)
    - Defining Raw Materials on Quarry
    - Calculate exploding energy
    - Accounting and Programming brick charge cost for each rotary kiln per year
    - Defining Operational Systems
    - Defining Quality and Management systems

- MARMARA UNIVERSITY – FACULTY of ENGINEERING
  - **Dean's Office – Assistantship** (10/ 2006 – 06/ 2007)
    - Regulation of Dean's Programme
    - Basic Office works

- KIMAR A.S
  - **Quality Control Department – Eng. Trainee in Laboratory** (07-09/ 2006)
    - Quality Control Methods of Raw Materials Laboratory Application
    - R&D Department and Product Quality Control Laboratory Application
    - Correcting Pigmentation of Product
    - Creating New Coating Colors

- BAYRAKTARLAR A.Ş
  - **Quality Control Department – Technician Trainee in Lab.** (07-08/ 2002)
    - Head Lambs Quality Controls Laboratory Applications

- KALE NOBEL INTERNATIONAL PACKING COMPANY
  - **Quality Control Department - Technician Trainee in Lab** (11/ 2001 – 04/2002)
    - Packaging Quality Control Methods Application
    - Coating Quality Control Methods Applications

- BURSA ÇİMENTO FABRİKASI A.Ş
  - **Quality Control Department – Technician Trainee in Lab** (09/ 1998 – 06/ 1999)
    - Quality Control Laboratories of Cement (physical , Chemical, Mechanical Laboratories Applications)

COURSE AND EDUCATION PROGRAMS

- RÖNESANS DEĞİŞİM BİLİMLERİ ENSTİTÜSÜ
  - **Developing Carier** (22-23.10.2011/2 days)
    - Leadership
    - SWOT analyzing
    - Strategy 1N 1 K (for whom and what)
    - Scenario 5 N 1 K (what, why,how,when, who do it)
    - Analyzing Target SMART
- RÖNESANS DEĞİŞİM BİLİMLERİ ENSTİTÜSÜ
  - **Strategy Scenario, Budget** (5-7.12.2011/2 days)
    - Coorperaion Budget
    - Program Budgeting And Basic Budgeting Principles And Techniques
- RÖNESANS DEĞİŞİM BİLİMLERİ ENSTİTÜSÜ
  - **Process, Meeting and Project Management** (12.11.2011/ a day)
    - Relationship Of Corporateresources And Processes
    - The main Competitive Strategies
    - Strategies of cost leadership
    - Process Management and Leadership
    - Techniques of problem solving
    - Management of Project
    - Methodology of Project Management (WBS) (MS-PROJECT)
- RÖNESANS DEĞİŞİM BİLİMLERİ ENSTİTÜSÜ
  - **Customer Relation Management** (22-23.10.2011/ 2 days)
    - One to one marketing, Customer Relations , Advanced Sales Techniques
    - Trends, General Terminology, and 4P Marketing

- TURK DIŞ TİCARET VAKFI
  - **Trade Specialist Programme** (2010/ 68hr.(8 weekends))
    - Customs Legislation
    - Export
    - Inport
    - Foreign Trade Of Correspondence Techniques
    - Risk of Foreign Trade
    - E – Trade
    - Outward Processing – Inward Processing

- KMO KOCAELI BRANCHE
  - **LPG Responsible Director** (2009/ 3 days)
    - LPG Market Responsible Director Regulation
    - Legal arrangements related to the LPG industry
    - Technical regulations and practices related to LPG,
    - Directorate responsible for occupational health and safety legislation,
    - Safety precautions and practices,
    - Fire-fighting and first aid,
    - Issues related to Human and Environmental Health,

- ANDA GROUP
  - **ISO 14001 internal Auditor Certificate** (2008/ 4hr)
    - Principles Of Auditing
    - Planning And Management Of Audit Programmes
    - Creating Control Program Aim of the Programme
    - Selection Of Audit Team
    - Auditors Identify And Develop Competencies Preparation Of Question Lists
    - Auditing Practice
    - Audit Reports And Corrective Action
    - Applied Control Applications (Planning, Control)
    - Certification And Accreditation

- ANDA GROUP
  - **ISO 9001 internal Auditor certificate** (2008/ 4 hr)
    - Principles Of Auditing
    - Planning And Management Of Audit Programmes
    - Creating Control Program Aim of the Programme
    - Selection Of Audit Team
    - Auditors Identify And Develop Competencies Preparation Of Question Lists
    - Auditing Practice
    - Audit Reports And Corrective Action
    - Applied Control Applications (Planning, Control)
    - Certification And Accreditation

- KMO ISTANBUL BRANCHE
  - **ISO 9001 : 2000 Quality Management** (2006/2 days)

- FEYZA EDUCATION CENTER
  - **English course** (2003 / 2 months)
    - Basic English courses
- YILDIRIM EDUCATION CENTER
  - **Computer Course** (1998/ a month)
    - Basic of MS Office

CONGRES AND SEMINARS

- Chamber of Chemical Engineering Istanbul Branch
  - 6. International Paint and Auxiliary Product Industry Congress and Exhibition (May 2006)
  - 7. International Chemical Engineering Congress (Semptember 2006)
  - Reach /CLP Legislation (October 2010)
- KALDER
  - 7. Symposium Quality and Success (April 2009/ 2 days)

LANGUAGE SKILLS

- English (Reading : 9/10 , Writing: 7/10 , Speaking : 7/10)

COMPUTER SKILLS

- Basic of PC Program
- MS Office (Word, Excel, PowerPoint, Access)

SOCIAL ACTIVITIES

- Chamber of Chemical Engineering Kocaeli Branch
  - Member
- Chamber of Chemical Engineering Istanbul Branch
  - Member of Student Commission of Student
- Marmara University
  - Member of Chemical Engineering Club
  - Technology and Research Club – Founder Member

INTEREST

- Voleyball (Marmara University Faculty of Engineering Ladies)
- Theatre (Kayıp Tiyatro ve Maskeli Oyuncular)
- Reading Book in Adventure, Science Fiction
- Fishing
- Making new tastes

PERSONAL DETAILS

Date an Place of Birth	: 06.10.1982 / BURSA
Civil Status	: Single
Driving Lisans	: B (23.09.2004)
Nationality	: TC