T.R.
EGE UNIVERSITY
Graduate School of Applied and Natural Science

OPTIMIZATION OF PAINT STRIPPING PROCESS, MODELING AND IMPROVING OF SCRAP RATIO

MSc Thesis

Buket ERBECER

Chemical Engineering Department

İzmir
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Supervisor : Prof.Dr. Süheyda ATALAY

Chemical Engineering Department

Chemical Engineering Second Cycle Programme

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EGE ÜNİVERSİTESİ FEN BİLİMLERİ ENSTİTÜSÜ

ETİK KURALLARA UYGUNLUK BEYANI

EÜ Lisansüstü Eğitim ve Öğretim Yönetmeliğinin ilgili hükümleri uyarınca Yüksek Lisans Tezi olarak sunduğum “Optimization Of Paint Stripping Process, Modeling And Improving Of Scrap Ratio/ Boya Söküm Süreç İyileştirınesi, Modellemesi ve Fire Oranının İyileştirilmesi” başlıklı bu tezin kendi çalışmam olduğunu, sunduğum tüm sonuç, doküman, bilgi ve belgeleri bizzat ve bu tez çalışması kapsamında elde ettiğimi, bu tez çalışmasıyla elde edilmeyen bütün bilgi ve yorumlara atıf yaptığımı ve bunları kaynaklar listesinde usulüne uygun olarak verdiğimi, tez çalışması ve yazımı sırasında patent ve telif haklarını ihlal edici bir davranışımın olmadığını, bu tezin herhangi bir bölümünü bu üniversite veya diğer bir üniversitede başka bir tez çalışması içinde sunmadığımı, bu tezin planlanmasından yazımına kadar bütün safhalarda bilimsel etik kurallarına uygun olarak davrandığımı ve aksinin ortaya çıkması durumunda her türlü yasal sonucu kabul edeceğimi beyan ederim.

19/09/2022

Buket Erbecer

PREFACE

My master's thesis is to develop an approach to increase production efficiency and reduce waste rates at the company where I work. As a result of this study, as an alternative method, reusability was increased by improving the process parameters after the paint removal process, and this method was provided by examining the quality performance.

I would like to enounce my thankfulness to Prof.Dr Süheyda ATALAY and CMS Jant ve Mak. San. and paintshop manager Koray Çınar.

İZMİR Buket ERBECER

19/09/2022

ÖZET

BOYA SÖKÜM SÜREÇ İYİLEŞTİRMESİ, MODELLEMESİ VE FİRE ORANININ İYİLEŞTIRİLMESİ

ERBECER, Buket

Yüksek Lisans Tezi, Kimya Mühendisliği Anabilim Dalı
Tez Danışmanı: Prof. Dr Süheyda ATALAY
Ağustos 2022, 54 sayfa

Bu çalışmada jant üretiminde fire oranlarında iyileşme sağlamak üzere boya söküm işleminin optimizasyonu hedeflenmiştir. Öncelikli olarak alüminyum alaşımlı jantların üretim süreci hakkında detaylı bilgi verilmiştir. Üretim sonucunda döküm, işleme veya boyama kaynaklı sebeplerle jantlar fire olarak ayrılabilmektedir. Jantların fire olarak ayrılmasının sebepleri incelendiğinde, boya söküm işleminde porozitenin öne çıkan etkenlerden birisi olduğu tespit edilmiştir. Boya söküm işlemi ile fire jantlar yeniden boyanarak bitmiş ürün olarak elde edilebilmektedir.

Jantların kazanılabilmesi için kalite performansından ödün vermeden mekanik, malzeme testlerinin kriterler içerisinde olması gereklidir. Bu sebeple tez çalışmasının birinci aşamasında sıcak sülfürik asitle yapılan boya söküm işlemine maruz kalan metalik ve opak boyanmış diamond ve cast surface jant çeşitlerinin mekanik ve malzeme dayanıklılığı test edilmiştir. Çekme, uzama, darbe, 13° darbe, yapışma, nem, su, sertlik, dinamik yorulma, cass testi yapılmıştır. Testlerin sonucunda jantların özelliklerinin istenen kriterler içinde kaldığı tespit edilmiştir. Çalışmanın ikinci aşamasında boya sökme işlemininin değişkenliklerinin etkisi test edilerek, fire oranında iyileşme sağlanması hedeflenmiştir. Optimum koşullarda minimum fire ile boya sökme işleminin verimliliğini sağlayarak, jantların kalite performansını kontrol etmek amaçlanmıştır.

Fire olan jantların sebepleri pareto analizi ile tespit edilmiştir. Öne çıkan sebebin porozite olduğu tespit edilmiştir. Diamond ve cast surface metalik ve opak boyanmış poroziteli jantlar farklı proses parametrelerine göre boya söküm işlemine maruz bırakılmıştır. Proses parametreleri olan sıcaklık (80°Cve 85°C), sülfürik asit konsantrasyonu (%96 ve %98) ve işlem zamanı (20 ve 25 dk) değişkenleri "minitab full factorial design" kullanılarak hazırlanmış ve analiz edilmiştir. Bunun sonucunda optimum proses koşullarında minimum porozitenin elde edildiği değerler tespit edilip know-how oluşturulmuştur.

Sonuçlar incelendiğinde boya söküm prosesi sonrasında 80°C sıcaklıkta, 25 dak işlem süresinde ve %98 konsantrasyonda sülfürik asitle boya söküm işlemi yapılan jantlarda minimum seviyede porozite gözlemlenmiştir. Porozite seviyesi mikroyapı analizi ile de tespit edilmiştir.

Anahtar Kelimeler: Alüminyum alaşımlı jant, boya söküm işlemi, malzeme ve mekanik testler, Boya testleri

ABSTRACT

OPTIMIZATION OF PAINT STRIPPING PROCESS, MODELING AND IMPROVING OF SCRAP RATIO

ERBECER, Buket

MSc.in Department of Chemical Engineering
Supervisor Prof.Dr Süheyda ATALAY
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In this study, it was aimed to analyze the conditions in wheel production and to improve scrap ratio. First of all, detailed information about the production process of aluminum alloy wheels were introduced. During the production process, wheels can be scrapped due to casting process, machining process or painting process. When the reasons for wastage of the wheels are examined, the effect of porosity is seen as one of the prominent problem. Scrap wheels can be repainted and obtained as a product after paint stripping process.

To recover the scrap wheels, material, mechanical and painting tests must be within the criteria without sacrificing the quality performance of wheels. In the first step of the study the mechanical and material durability of two types of wheels which are cast surface wheels and diamond cut wheels were tested. Tensile test, elongation tests, 13° impact test, dynamic fatigue test, cass tests were carried out. The test results were obtained within the customer expectations. In the second step of the study, it was aimed to improve scrap ratio by testing the effect of the variability on the paint stripping process and to control the quality performance of the wheels by ensuring the efficiency of the paint removal process with minimum waste under optimum conditions.

The reason causing the diamond cut and cast surface scrap wheels were determined by pareto analysis. It has been determined that the major reason is porosity. Porous wheels were subjected to paint stripping process in different process conditions. The process parameters were selected as temperature (80°C and 85°C), sulfuric acid concentration (96% and 98%) and operation time (20 min and 25 min). Process variables were analyzed using Minitab20 full factorial design. As a result, the values at which the minimum porosity was obtained under optimum process conditions were determined and know-how was created.

When the results were examined, a minimum level of porosity was observed in the wheels which the paint stripping process was performed with sulfuric acid at a concentration of 98% at 80°C at 25 min. The porosity level was also determined by microstructure analysis.

Key words: Aluminum alloy Wheel, paint stripping process, material and mechanical test, Paint test

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SYMBOLS AND ABBREVIATIONS

Symbols	Definition
Al	Aluminum
Ar	Argon
H	Hydrogen
N	Nitrogen
Mg	Magnesium
Si	Silicon
Ti	Titanium
Zn	Zinc
μ	micron
CNC	Computer Numerical Control
ET	Einpresstiefe
OEM	Original Equipment Manufacturer
ppm	parts per million
PCD	Pitch Center Diameter
LPDC	Low Pressure Die Casting

1. INTRODUCTION

About 100 years ago, at the dawn of the automobile industry, cars were coated with a varnish-like substance that was rubbed onto the vehicle's surfaces. This coating was then scraped and buffed, and the varnish was resubmitted and polished to create multiple layers of the coating. After applying many coats of varnish, the automobiles were polished to create gleaming surfaces (Akafuah et al.,2016).

According the sector report of Association of Turkey Casting Industry, domestic aluminum alloy production wheels increased 400 times from 20000-25000 wheels per year to 9 million wheels per year in 25 years. There are six manufacturers of aluminum wheels, two of which are foreign investor. The facilities employed over 2500 qualified employees. In 2011, those six plants have reached an installed capacity of 9,500,000 units per year and production was made 95% capacity. In this year, 80% of production was for OEM's (Original Equipment Manufacturer) and the others were for aftermarket (Dal, 2012).

Figure 1 Aluminum Alloy Wheel

The aluminum wheel in Figure 1 has an advantage over steel rims in terms of efficiency and fuel economy because it is lighter. Due to its small weight, it enhances steering wheel control, driving dynamics, and vehicle stability.

As reported by the European Aluminum Association , at the year 2012 the average amount of aluminum for car produced in Europe was three times the quantity registered in 1990. Wheels are one of main parts where aluminum alloys are applied, together with car frame and car engine parts. As recorded, in fact, the use of light alloys for wheels production in the European market in the year 2000 covered about 30-35% of cars, while at the year 2011, about 50% of the vehicles produced on a worldwide basis used aluminum wheels (Tocci et al., 2015).

During the manufacturing process of wheel, some of the defects may occur. The purpose of this thesis to increase the productivity by recovering some of the wheels using paint stripping process. The performance of paint stripping process is examined with mechanical and material tests after paint stripping process. By this way, the optimum process conditions are determined.

In this frame, the main goal of this thesis project is:

- Firstly, paint stripping process is applied for the cast surface and diamond wheels. By the way mechanical and material tests are checked.
- After that, the scrap ratio was analyzed on the basis of defect type and model type. It was seen that the main defect is porosity.
- Minitab20 design of experiment tool was used to select optimum paint stripping parameter.
- The effect of parameters is analyzed.

2.THEORETICAL BACKGROUND

Aluminum is an alloy with appealing qualities including low density, high reliable capabilities, and high resistance to corrosion that really is compatible with current manufacturing processes.

Cu, Si, Mg, Zn, and Mn are the most crucial alloying components that are usually added to pure aluminum (99.5%). All aluminum alloys have greater tensile strength, yield point, and stiffness as compared to pure aluminum (Kridli et al.,2010).

The advantages of aluminum wheels can be summarized as:

- The use of aluminum enhances the lifespan of tires and brake linings by quickly transferring the heat generated on the tire and brake system.
- Increases braking distance as well. A broader tightening space is present on the studs connecting the wheel to the axes. The chance of stud loosening is decreased.
- Wheels made of aluminum alloy are all one piece. There is no chance of the cover dislocating during movement because it is not covered in plastic like steel rims are.
- It has a strong ability to hold a balance.
- It improves safety and comfort while driving. It is beautiful.
- There is a wide range of models as well. It doesn't corrode.

Wheel production process changes according to wheel diameters, wheel type. The cross-sectional area of a rim is detailed in Figure 2 and its main parts are explained.

Flange: It is called the tire sidewall that contacts the rim. Without the flange, the rim cannot be expected to fully hold the sonic. It is available in different types of systems.

Rim Width: The unit of measurement used to measure width is inches. The width of the rim varies from 5 inches to 15 inches.

Rim Offset: It is the length of the distance from the inner hub of the offset wheel, the size of which varies between -50 mm and 70 mm, to the middle of the rim. The offset range of most wheels varies between 20 and 60.

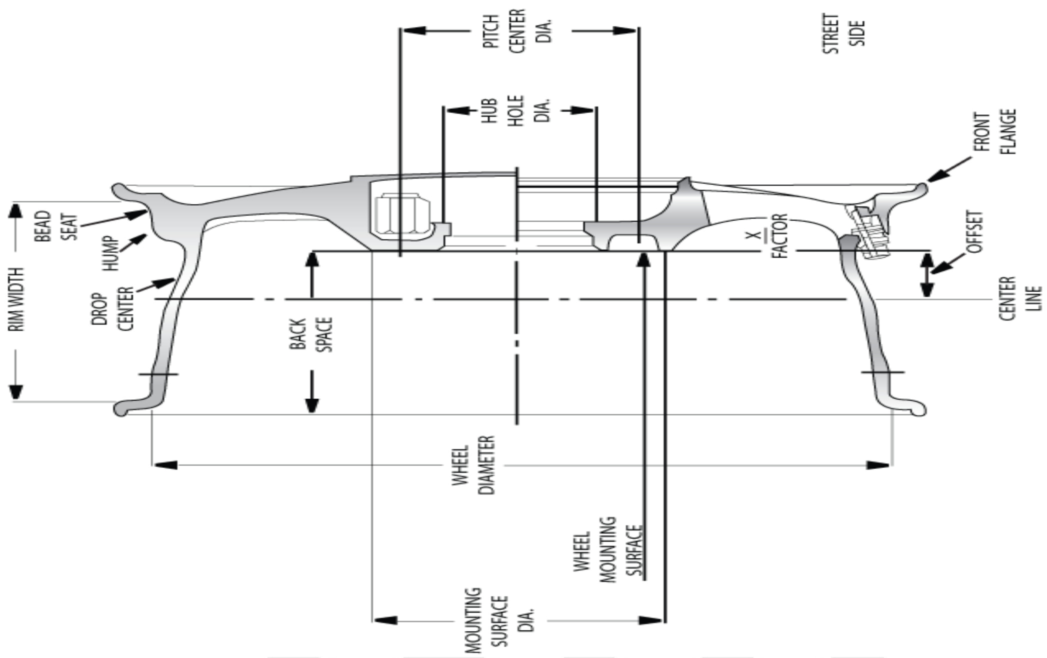


Figure 2 Wheel Cross Section (Wheel specialist, 2022)

In general, wheel production process consists of the following steps: Casting, machining and painting.

Casting → Machining → Painting

2.1 Casting Process

The casting process consists of the following steps:

Melting → Degassing → Low Pressure Die Casting

2.1.1 Melting and Degassing

The quality of the molten metal is frequently very excellent and contains little hydrogen gas and impurities. This is particularly true if the melt is melted and gased in the same furnace that will fill the melt under pressure.

The molten material used for casting comes from the center of the furnace, where oxides and inclusions tend to fall to the bottom or rise to the surface, contributing to the excellent metal quality. By pressurizing the furnace, it is possible to avoid breaking through the melt surface and swirling some of the surface oxides back into the melt when transferring metal from the furnace to a ladle.

Three different types of operations are required when melting Al alloy for die casting: melting of fresh ingot, remelting of foundry and trimming scrap, reconstituting this melt with appropriate additions, and storing quantities of molten metal at a tightly controlled temperature.

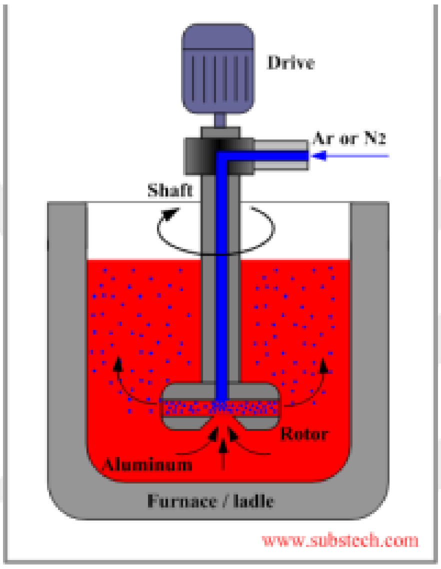


Figure 3 Melting And Degassing Process

In Figure 3 degassing process is shown. Moisture introduces hydrogen. Due to porosity and general shrinkage, too much hydrogen has a negative impact on the mechanical characteristics of produced aluminum. During melting and pouring, it's crucial to get rid of extra hydrogen. Hydrogen can be eliminated from molten metal by adding inert gases like argon or nitrogen. Hydrogen diffuses into the inert gas bubbles as they ascend through the molten aluminum and completely vanishes (Boyer and Gall, 1995).

2.1.2 Low Pressure Die Casting

The most common production technique for the creation of light alloy wheels is the low-pressure die casting (LPDC) process, as depicted in Figure 4. Low pressure casting processes have several advantages.

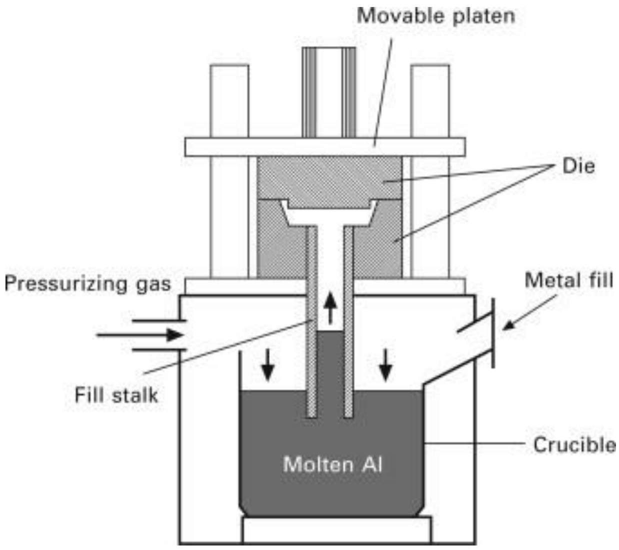


Figure 4 Low Pressure Casting Process

Metal is fed through the casting's bottom and up through the casting to complete the casting process. This provides you with more control over the fill rate than gravity casting does, reducing turbulence and oxide development. The bottom of the casting includes pressurized molten metal, which is accessible to appropriately feed the casting and lessen the amount of shrinkage present. As a result, solidification occurs from the top of the casting to the bottom.

The procedure is quite adaptable and can be utilized with metal dies, sand molds, or combos of both. A number of 2.0L-3.0Laluminum cylinder heads have been manufactured utilizing an LP semi-permanent mold system, where the cylinder head's exterior portion is formed by a metal die and its inside channels are made by sand cores (Kridli et al.,2010).

The fact that most aluminum casting alloys shrink by 3-6% during solidification presents a problem. Porosity may exist within the casting or at the surface if this shrinkage is not adequately compensated for by the addition of more feed liquid.

Due to its extremely poor solubility in the solid, it can potentially produce porosity during solidification. Therefore, it might be necessary to degas the molten metal for high integrity applications by either bubbling inert gas through it or by adding certain tablets that can either react with or remove the hydrogen from the molten metal (Otarawanna, 2011).

After low pressure casting process, to detect the defects x-ray control is necessary.

2.1.3 X-Ray Control of casting

In the production of aluminum alloy wheels, real-time radiographic inspection (RTR) is a technique to find small flaws. Figure 5 depicts the fundamental system. In this setup, X-ray is employed to find the flaws (Kumar et al., 2015).

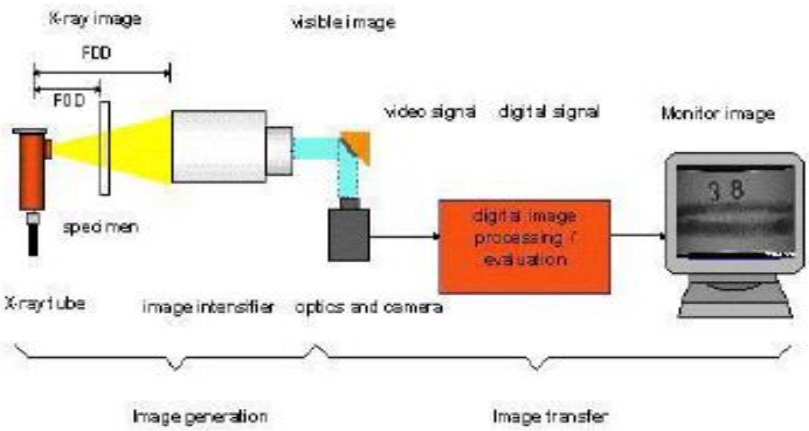


Figure 5 X-Ray Control of Casting

2.1.4 Heat Treatment Process

Heat treatment is a term used to describe a thermal event that causes desirable mechanical qualities by inducing microstructural changes. Heat treatment can actually affect strength and other mechanical qualities, increase hardness, improve wear resistance, reduce residual stresses, and adjust other mechanical properties. Heat treatment specifically refers to the strengthening of parts through precipitation hardening in aluminum alloys. Some non-heat treatable alloys can be strengthened by working them harder, while others can be strengthened by softening (annealing), solution treatment, and/or quenching operations under certain circumstances (Rashed et al., 2017).

2.1.5 Casting Defects

Figure 6 displays a fish-bone diagram. As depicted in the figure, casting faults are caused by pressure, time, alloy, casting, and mold. Internal porosity occurs as a result of most casting processes. Due to the speed of the process, the turbulent metal flow, and the potential for gas entrapment, this issue is typically most noticeable in pressure die castings.

In general, porosity in castings needs to be avoided and regulated to prevent negative impacts on their mechanical qualities, pressure tightness, and surface finish, especially if machining is required. Every attempt is made to concentrate porosity in risers or to spread it uniformly throughout a casting as less hazardous micropores by paying attention to mold design and controlling casting conditions. Shrinkage, internal oxide film development, and gas entrapment are the main causes of porosity (air, steam, dissolved hydrogen, or products derived from the burning of organic lubricants). Due to the very turbulent metal flow and quick solidification rates in pressure die castings, porosity is typically at its worst; however, the entrapment of gases can be avoided by emptying the mold before the molten metal enters it (Polmear et al., 2017).

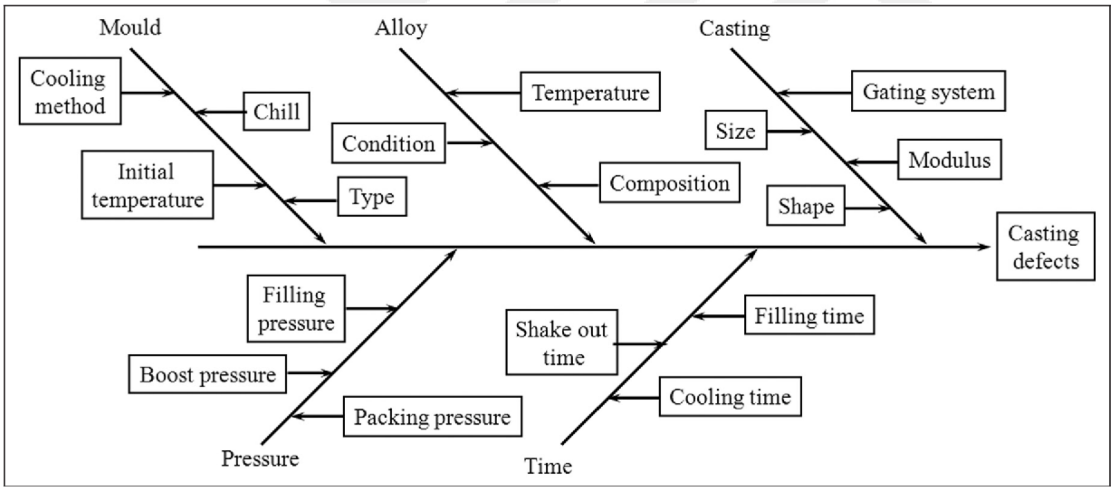


Figure 6 Casting Defects (Wang et Al., 2014)

The porosity can greatly diminish the casting's mechanical qualities, pressure tightness, machinability, and overall look. Therefore, as a part of the casting, feeders are precisely and strategically developed to supply liquid to the final areas to solidify. Only hydrogen has a sizable solubility in molten aluminum.

2.2 Machining Operation

In this procedure, the cap, wheel bolt, and valve of the wheels made using the low pressure casting method are drilled in order to create the necessary tire cross-section form.

Wheels that have been heat-treated are delivered to a machine shop. Depending on the selected machining tools, CNC programs are created in accordance with technical drawings. The hub mating surface, spoke back surface, inner flange, center hole, and inner tire contact surfaces are machined in the first of three operations that make up the machining of the wheels. After the outer rim component, tier mating surfaces, and the inner flange are machined, the wheel is secured to the chuck.

Drilling valve holes is done next, and then the lug holes are machined and chamfered as a final step. Wheels are submerged in water and tested for helium leaks. Following these steps, the painting shop receives the required wheels. Whether the leakage is below or over a leakage threshold is determined through helium leak testing. If it exceeds the cutoff, the wheel must be detached and sold as scrap.

2.3 Painting Process

The main steps of panting process cast wheels surface treatment, powder coating, wet painting and clear coaing.

The painting has two important roles, one is to protect the substrate materials from corrosion and the other is to improve the appearance quality.

The curing cycle is typically combined with the heat treatment needs for the casting in painting techniques where the paint is fixed by heat, such as powder coating, and represents the final heating stage (the product's aging).

2.3.1 Surface Treatment

Degreasing, rinsing, deoxidation, and passivation are the primary activities that make up the typical pretreatment procedure for wheels. In Figure 7, it is depicted.

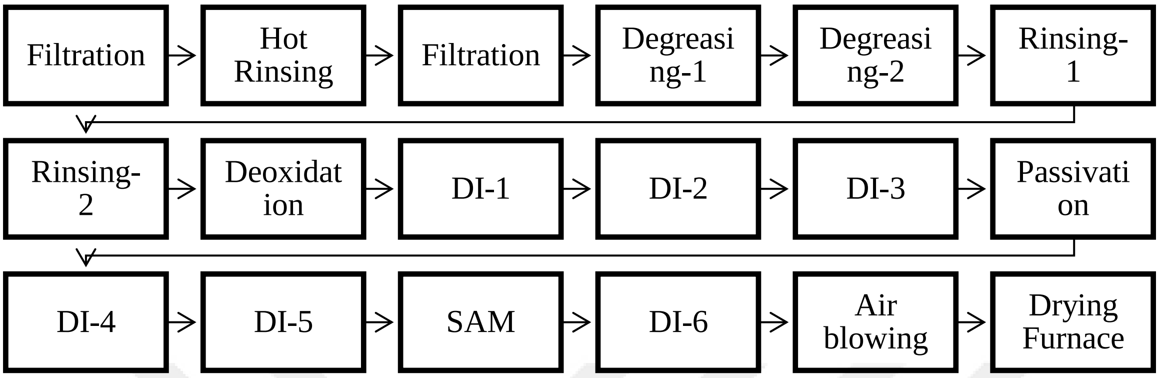


Figure 7 Pretreatment Process Flowsheet

***Degreasing*:** Inorganic salts—the "builder"—and organic substances—the "surfactants"—make up alkaline degreasers. Removing inorganic and pigment impurities like metal particles and welding pearls is the builder's main responsibility. The surfactant's job is to get rid of soaps, oils, lubricants, and other organic pollutants.

Commonly used ingredients in alkaline cleansers are

NaOH, KOH, Na_2CO_3, K_2CO_3 →maintain alkalinity

- Silicate minerals → elimination of particles, blocker, and buffer
- orthophosphates→degreasing
- condensed phosphates→degreasing, complexing
- complexing agents→complexing

Both a hydrophilic group, which is often a long chain of ethoxy (EO) or propoxy (PO) molecules, and a hydrophobic group, which is typically a lengthy chain alkyl, are found in surfactants. They come underneath the categories of amphoteric, cationic, anionic, and nonionic surfactants.

Due to their higher protecting environment, nonionic surfactants are generally used in degreasing today. Surfactants in solutions lower interfaces pressures, adsorb at solid interfaces, and form micelles because of their amphiphilic traits. Figures 8 and 9 depict the technique of oil removal from surfaces. Prior to lowering surface tension and removing separated droplets containing oil from the surface, the agents immediately adsorb on the oil surface.

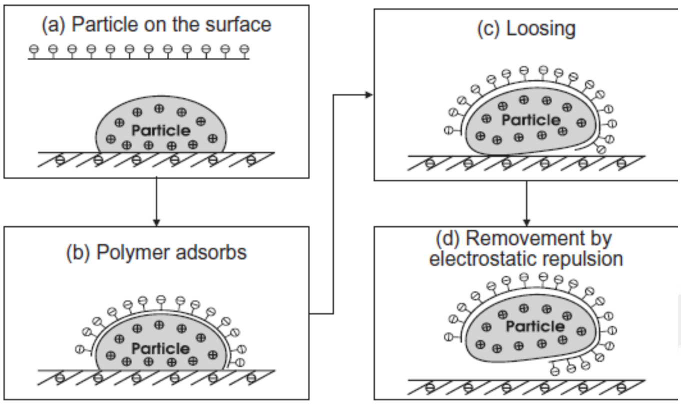


Figure 8 Mechanism of Particle Removal from Surfaces

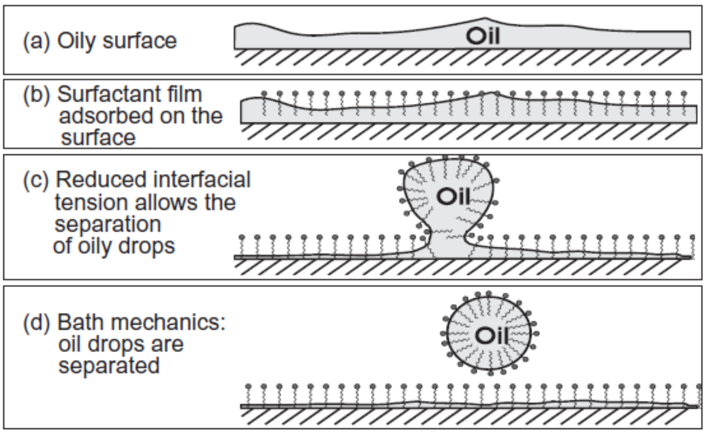


Figure 9 Mechanism of Oil Removal from Surfaces

Distilled water is desirable in order to prevent the deposition of calcium and magnesium salts, although water from the city supply can also be added to the bath to keep it level. Titration techniques, such as total alkalinity, free alkalinity (optional), conductivity, and pH (optional), are mostly used to manage rust remover tubs (Streitberger and Dössel, 2008).

***Rinsing**:* Between the cleaning and following coating phases, rinsing cleans the surface of surplus reagents, prevents cross-bath contamination, and reduces the amount of chemical bath agents that are consumed. To achieve full elimination of surplus base, two aqueous rinse steps—one preliminary and one final—are commonly included between alkaline cleaning and a deoxidation. In order to replenish the alkaline reagent in the bath, rinse water is recycled to earlier stages (Schuman, 2018).

Passivation: Zirconium-based post rinses are typically operated under the following conditions:

- zirconium concentration 50–150 ppm
- fluoride concentration 50–200 ppm
- pH 3.5–5.0
- conductivity(20 ◦C) <600 μS cm^{-1}
- control: pH, conductivity, Zr content and/or total acid titration
- preparation in demineralized water
- dump frequency 1–4 weeks, depending on contamination level and quality of preceding rinsing bath (Streitberger and Dössel, 2008).

2.3.2 Powder Coating

The use of dry, particle solids (often referred to as "powder") coatings in place of liquid coatings as a means of reducing VOC emissions. In comparison to other paint systems, their compositions have volatile solvent concentrations of only 2% or less. Wheels, bumpers, hubcaps, door handles, cosmetic trim and accent pieces, truck beds, radiators, filters, and numerous engine parts are currently powder coated in the automobile sector.

Surface coatings made of resins, pigments, and fillers are called powder paints. This procedure employs the application of electrostatic powder paint. Guns are used to spray guns of negatively charged paint onto the grounded rim. Homogeneous covering is a characteristic of powder paint. It is negatively charged as it leaves the sprayer. According to the idea that opposing poles attract one another, paint particles are drawn to one another via electrostatic attraction. They resist one another because they all share the same charge, resulting in a homogenous distribution. As seen in Figure 10, the "Faraday Cage effect" occurs when electrostatically coating charged components with sharp interior corners or recesses. As a result of the "effect," powder from a cannon cannot enter the crevices and corners because they are uncharged.

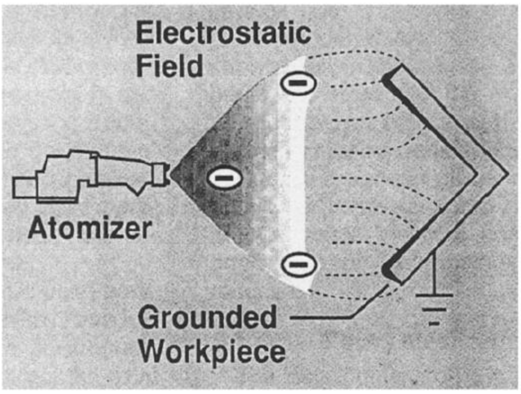


Figure 10 Faraday Cage Effect

Thanks to redesigned, cutting-edge delivery methods, the electro spraying coating method provides an effective transfer of coating to the parts, resulting in a smooth, reliable film bond. The analyte solution is fed via a capillary that is held at a high voltage during the electrospray procedure. As the solution emerges, the strong electric field has the effect of producing a mist of highly charged droplets that travel along a potential and pressure gradient in the direction of the mass spectrometer's analyzer. Fully desolvated ions are produced when the solvent completely evaporates or when the charged droplets undergo field desorption (Miranda et al., 2014).

In the automotive and electrical appliance industries, electrostatic powder coating is a common method of putting a protective surface covering to metallic surfaces. Through corona or tribo-charging, specific paint particles are artificially charged before being sprayed using high pressure atomizers. In Figure 11, a typical transfer efficiency is displayed. Any grounded substrate exposed to the aerosol picks up an induced electrical charge that is equal and opposite to its own. Because opposites attract, the paint particles are drawn to the surface (Thomas et al.,2009).

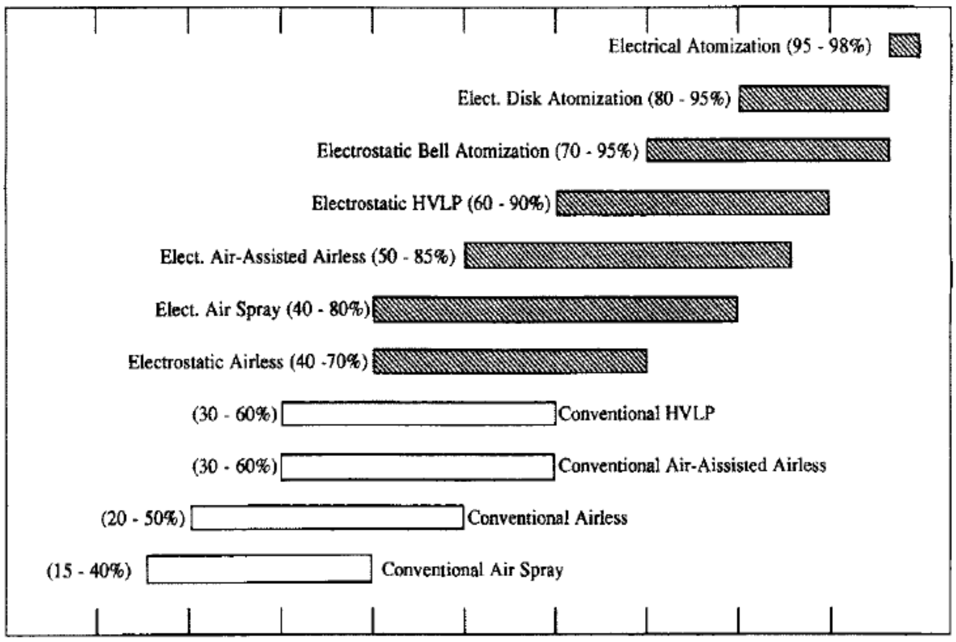


Figure 11 Typical Transfer Efficiencies for Various Electrostatic and Conventional Spray Processes

Transfer effectiveness is the key advantage of an electrostatic painting technology. Electrostatic bells can reach a high transmission efficiency of more than 90% in some situations. Due to little overspray, this great efficiency results in significant cost savings. A feature of electrostatic finishing known as "wrap" enables certain paint particles to be drawn to the rear of this workpiece as they pass by, improving transfer efficiency even more. The cost of disposing of hazardous waste is reduced and VOC emissions are decreased through increased transfer efficiency. Reduced spray booth maintenance and cleanup (Rupp et al., 2010).

2.3.3 Base Coat

Similar to how the priming surface is applied, the base coat—also known as the color coat—is sprayed on. In automotive plants, robotic arms with pre-programmed spraying patterns are frequently employed.

The main binder is often an acrylic- and/or polyester-based core shell emulsion polymer. Melamine resins of the butylated or HMMM types serve as cosolvents or reactive diluents. Melamine and the binder interact during the baking of the clear coat, which results in some cross-linking of the base coat film.

To enable effective atomization, or the correct droplet formation, the viscosity needs to be very low at the spray nozzle or bell edge where the shear rate is maximum. The rheology of the solvent bone base coat is shown in Figure 12. To permit the flake orientation process as the droplet strikes the surface of the vehicle and deforms and flattens out, the viscosity must be low once more. The viscosity returns to high levels and the shear rate drops to zero after this leveling is complete, preventing the paint from sagging.

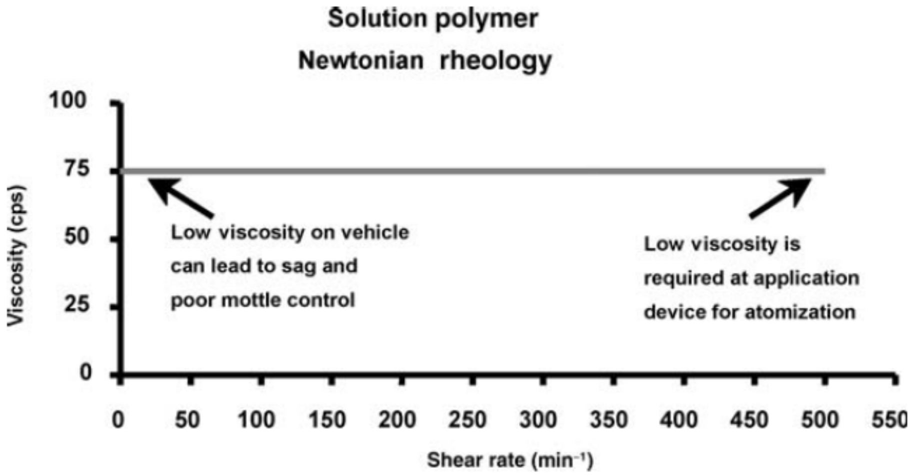


Figure 12 Rheology of Solventborne Base Coat Without Rheology Control

2.3.4 Powder Clear Coat

Due to their advantages for the environment, such as the lack of VOC emissions during application, powder clear coats are becoming more used in the wheel business. In addition, powder clearcoats provide additional benefits, such as:

- Direct recycling—overspray powder can be collected and be reused in the original coating process;
- No wastewater or paint sludge produced during their application;
- No need to use organic solvents for cleaning of application equipment or spray booth
- Reduction of the total energy used during application because the air supplied to the spray booth can be recycled;
- No VOCs produced and very low toxic aspects

- Uniform film thicknesses and similar appearance on horizontal and vertical surfaces (Akafuah et al.,2016).

2.3.5 Liquid Clear Coat

These are currently solvent-borne, but significant research is being done to create a waterborne clearcoat that is strong enough for automotive applications.

The clearcoat, the final coating, gives the overall coating longevity, environmental etch resistance, and scratch resistance. It gives a gloss and depth that might not otherwise be as vibrant and guards against damage like fading brought on by UV rays from the sun. Additionally, the clearcoat facilitates maintenance and repairs.

The most popular paint used in the automotive sector is the 1K acrylic melamine clearcoat due to its excellent cost-performance ratio. It commonly uses acrylic polyols (Ac) and amino cross-linking agents as its foundation (MF, melamine resins). The clearcoats acrylic melamine silane and carbamate melamine both have increased etch and scratch resistance. The 1K and 2K epoxy acid clearcoats are among the most widely used clearcoats in terms of acid etch resistance, while both 1K and 2K polyurethane clearcoats provide an outstanding mix of etch and scratch resistance. Epoxy acid clearcoats have a rather short shelf life when created as a 1K system, nevertheless.

Since they are UV stable and can be utilized in a variety of applications, acrylic polymers have long been a staple in the coatings business. Because there are so many acrylic monomers available, basic acrylic free radical polymerization can be used to create copolymers of many sorts. Similar to this, there are several side-groups for acrylic monomers that enable crosslinking chemistries with numerous other polymer materials (Bierwagen et al.,2017).

Bright Machine Process

Bright machine operation is applied for diamond wheels. After this process, their surface looks shiny. Process steps are different than cast wheel are shown in Figure 13.

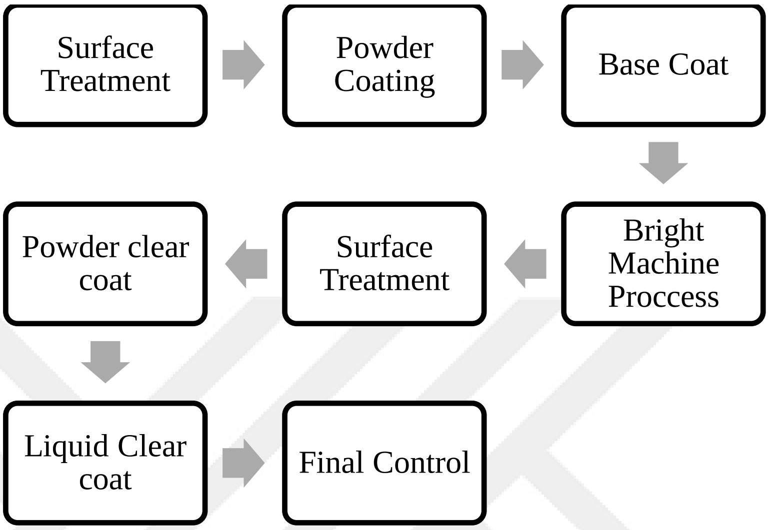


Figure 13 Process Steps of Diamond Wheel

2.4 Paint Stripping Process

In the market for aluminum wheels, paint stripping often entails chemically removing paint from the surface. Significant technological, environmental, and/or safety limits are present in these procedures (Rousseau et al., 2013).

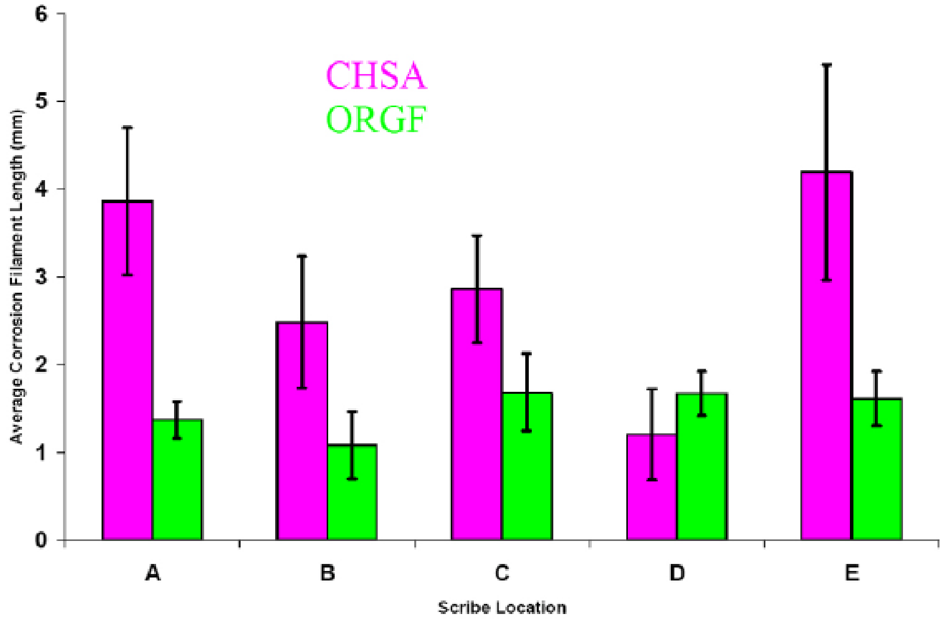
The following methods and circumstances are used when removing a sample of paint:

- Methylene chloride (MC), In this application, a low-temperature boiling point solution is applied at ambient temperature. It has been chosen to be one of the highly sophisticated procedures that are used in industry.
- 60± 5 °C of condensed heated sulfur (CHSA), a typical acid in this use. It has been chosen as that of the market average. This strong remover etches aluminum even though it is particularly successful at removing organic coatings.

- HTIP, or elevated temp artificial procedure, runs at 400± 50 °C. One of the industrial cleaners chosen to be used on some replacement wheels is this particular one.
- Organic fluid (ORGF), at 150±10 °C, free of VOCs, HAPs, and etchants. It has been chosen to be one of the internationally accepted OEM widely used procedures.

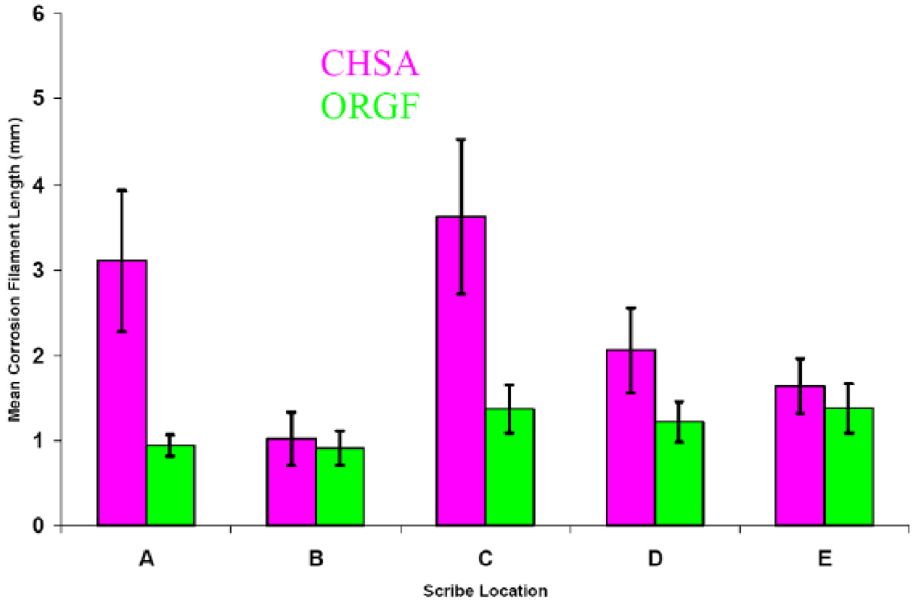
Methylene chloride and concentrated hot sulfuric acid are used in the two most popular methods.

The overall performance of the MC, CHSA, HTIP, and ORGF procedures is improved by pretreatment. Five distinct locations, A, B, C, D, and E, were scribed on the re-coated aluminum wheel pieces. However, the results are still very dispersed among the five scribed areas. CHSA with an additional pretreatment before re-coating exhibits better outcomes than without pretreatment. These scattering could be connected to the increase in roughness during stripping. It might be essential to take an additional step to polish the surface prior to pretreatment. These outcomes are displayed in Figures 14 and 15 (Rousseau et al., 2013).



(a)

Figure 14 CHSA&ORGF Average Corrosion Filament Length

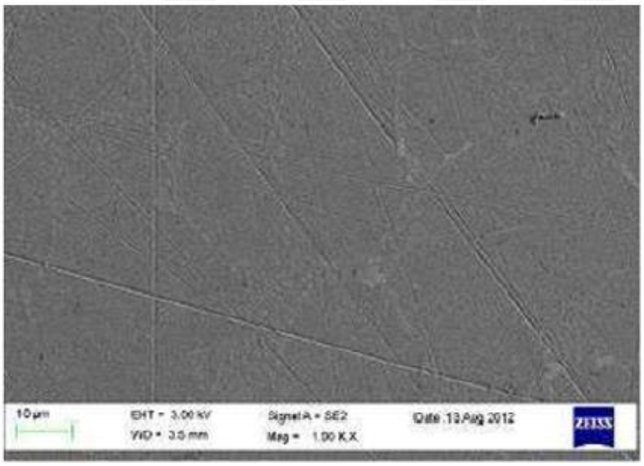


(b)

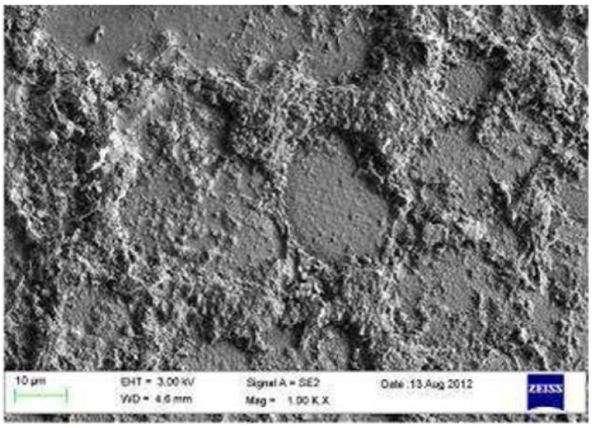
Figure 15 Mean Filiform Corrosion Filament Lengths for CHSA And ORGF (A) Without Pretreatment And (B) With Pretreatment

Figure 16 Scribe areas A,B,C,D

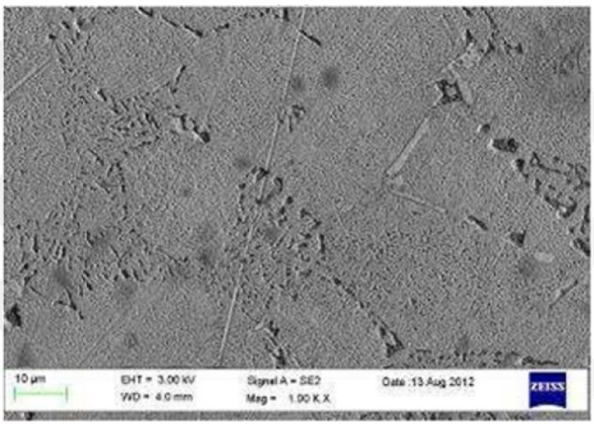
Figure 16 depicts the scribe regions A, B, C, D, and E for testing filiform corrosion. The panel portions removed with MC and ORGF still have grinding marks visible. This observation provides unequivocal proof that, in contrast to the other two procedures, these two processes preserve surface finishing. Figure 16 displays FE-SEM micrographs of the surfaces that were removed by the various processes.



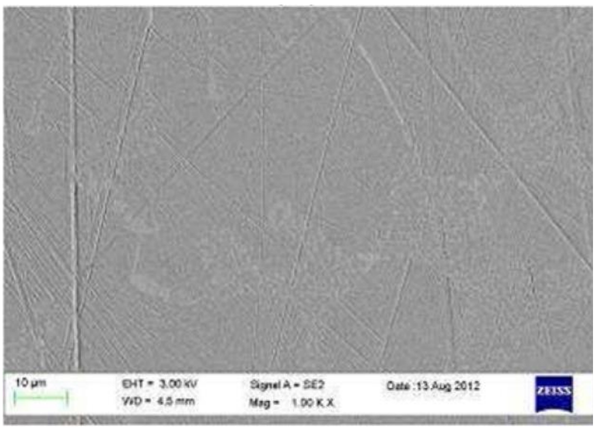
(A) Methylene chloride (MC)



(B) Concentrated hot sulfuric acid (CHSA)



(C) High temperature inorganic process (HTIP)



(D) Organic fluid (ORGF),

Figure 17 FE-SEM Micrographs of The Surface of The Aluminum Wheel Pieces After Stripping In (A) MC, (B) CHSA, (C) HTIP And (D) ORGF

Alternative paint stripping processes are sandblasting, stripping with laser light and chemical strippers.

Sandblasting

Sandblasting should be used on a body before such a paint coating is applied. While sand serves as the most popular abrasion, other finer substances may also be used, including steel slag, shots, glassware, metals, ice, garnet (a mineral), and pieces of other vegetation.

Prior to adhesive bonding, it is frequently advised to sandblast the surfaces of a variety of steel, titanium or titanium complexes, alloy, polymers (polyester, polyethylene), or composite materials are examples of building components (Rudawska et al., 2016).

By adjusting the applied stream pressure and grit diameter to the particular substrate material, sandblasting can provide a surface with the requisite roughness attributes for subsequent adhesive bonding methods (including adhesive joining or painting). The dry ice is normally delivered to the blasting hose from a container that is typically attached to the sandblasting machine. Contained air "drives" the cannon while simultaneously creating negative compression and gently guiding the dry ice granules from the tank to the gun. The combination is then forced to move to a speed of around 300 m/s by a highly powerful jet system.

Stripping with Laser Light

Recycling materials enables environmental protection by lowering unnecessary waste while significantly raising operational costs. In Figure 18, the schematic view is displayed.

Epoxy-polyester hybrid coating removal by laser now offers a significant improvement over more conventional techniques including chemical paint removal, plastic bead blasting, and flame removal. The literature contains a number of uses for various laser systems in the paint stripping process (Barletta et al., 2016).

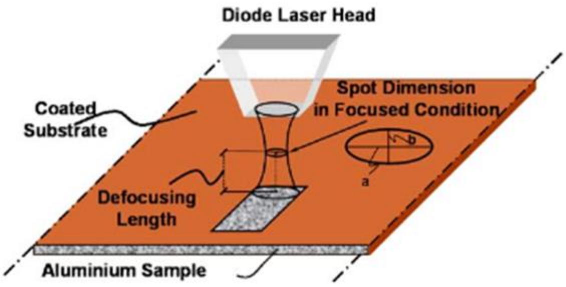


Figure 18 Schematic View of The Employed Experimental System

Chemical Strippers

A caustic substance, whose main purpose is to soften the paint coat, makes up the majority of chemical stripping agents. Phenol or organic acids are typically used to remove paint in order to prevent corrosion caused by the creation of metal hydroxides when sodium or potassium hydroxide is present, such as corrosion of metals like aluminum, copper, and tin and their alloys.

Methylene chloride, or dichloromethane (CH_2Cl_2), is the solvent most widely used in paint strippers since it is not flammable. (Charetton and Vincent, 1997).

Figure 19 Paint Stripping Process

As shown in Figure 19 paint is removed from wheel by using concentrated hot sulphuric acid. In this study, the method of concentrated hot sulfuric acid was chosen. The process parameters are shown in Table 5. Concentrated hot sulfuric acid and organic fluid were the only two methods that did not use methylene chloride and did not compromise the mechanical integrity of the aluminum wheel in terms of paint performance.

3. METHODS AND APPLICATIONS

This study consists of four main steps;

1. Use of lean manufacturing system for analysis of scrap ratio. (Fish-bone diagram, pareto chart)
2. Preference of paint stripping to reduce the scrap ratio,
3. Evaluation of the quality performance: mechanical and material test results must be in limits (Brinell hardness test, Scratch test, Tensile strength, Filiform corrosion).
4. Determination of optimum paint stripping process parameters to increase the productivity (Minitab20 full factorial design-response optimizer tool).

3.1 Use of Lean Manufacturing System for Analysis of Scrap Ratio

Lean manufacturing analyzes the process best from the point of waste disposal in a production system. When we confer about waste in the study, it refers to anything that does not add any value to the end-product. Correspondingly, lean manufacturing has a main objective to hold an industrial process that allows a well manufactured end product, which is precisely what the client needs while minimizing all non-value-added production operations

Analyzing potential origins of an undesired outcome is important once a flaw, mistake, or issue has been found and isolated for further research. Once an issue has been identified, its causes should be ascertained. The fishbone diagram (also known as a cause-and-effect diagram) is a helpful tool for identifying potential reasons in circumstances like these where causes may or may not be clear.

Fish-bone Diagram: The Fishbone diagram, which pinpoints the issue, reveals all pertinent components and their interactions with flaws. As a result, choosing the appropriate location for data collection and processing is straightforward. In order to categorize errors in the wheel production system, the fishbone diagram is used.

Pareto Chart: The pareto chart indicates that the casting and painting procedures are the main causes of problems. Finding the main issue is the first step. The three primary methods of producing wheels are casting, machining, and painting. Problems were categorized using production phases.

The wheel improves driving comfort and security. The samples were subjected to tensile tests and hardness measurements in order to evaluate their mechanical characteristics.

Brinell hardness testing, scratch tests, and tensile tests were completed on cast surface and diamond cut wheels.

3.2 Preference of Paint Stripping to Reduce Scrap Ratio

Concentrated hot sulfuric acid (CHSA), was used as an acid in this application. During the process factors affecting the process, temperature, time and concentration, were analyzed.

Paint stripping parameters are summarized in Table 1.

Table 1 Paint Stripping Process Parameters

Process Parameters	Max	Min
Temperature	85°C	80°C
Time	25 min	20 min
Concentration	% 98	%96

3.3 Evaluation of Quality Performance

After the paint stripping process, it is essential to verify the effectiveness of the wheels. As a result, all performance tests are required to comply with customer specifications.

Brinell hardness test

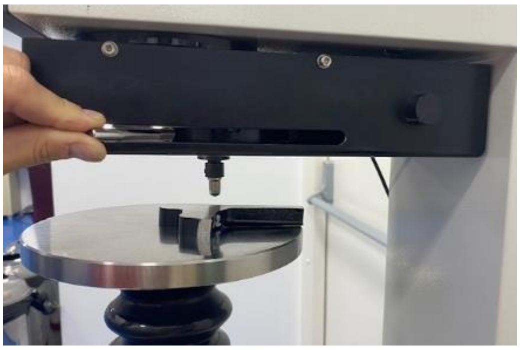


Figure 20 Brinell Hardness Test

Heat treatment and hardness are closely associated because of the homogeneity of the matrix, Mg and Si solubility in alloy, and their precipitation behavior. The easiest way to define hardness is as a material's resistance to being pierced or intended by something much harder. To increase indentation resistance, materials may undergo plastic deformation (as in metals and alloys), elastic deformation (as in rubber), elastic-plastic deformation (as in ceramics), or even crack propagation energy. As seen in Figure 20, the Brinell hardness test is carried out. The Brinell hardness test entails utilizing a ball made of hardened steel or tungsten carbide with a diameter of 5 or 10 mm to apply a constant force to a work piece's flat surface for 10 to 30 seconds. The range of the hardness test is between 80 and 110 HB 5/250 (D=5 mm ball, 250 kg, 2450 N stress).

Scratch Test

The scratch test has been employed for many years to evaluate coating/substrate adhesion. The two categories of test results are Gt5 and Gt0. The top outcome, Gt0, is shown in Figure 21. The cutting tool creates parallel lines on the wheel's front surface. The surface, which was deliberately divided for the adhesion test, is adhered to by the tape. Five minutes after the process is finished, the surface's tape is removed.

Under increasing loads, a diamond stylus is drawn over the coated surface until a clearly defined failure takes place at what is commonly referred to as the critical load in the test's conventional setup. Failures include separation of the coating, through-thickness cracking, and plastic deformation or cracking of the substrate or coating.

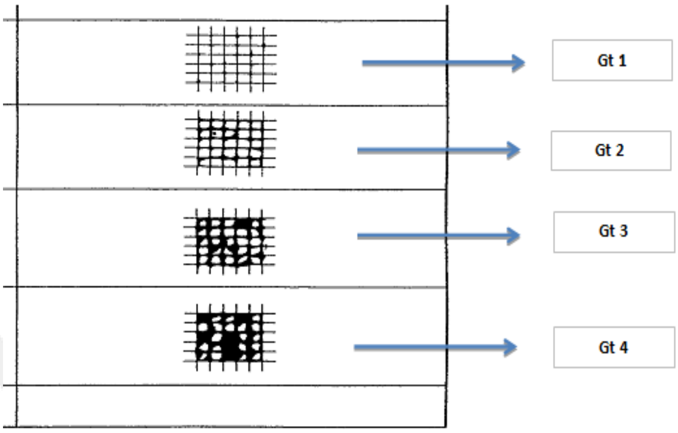


Figure 21 Scratch Test

Tensile Test

When creating the sample, a piece is cut with a saw from the spoke, outer flange, and inner flange, as shown in the picture by taking a quick look at the product picture. Samples are connected between the two parts of the device, as shown in Figure 22.

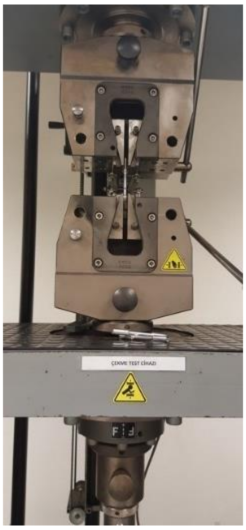


Figure 22 Tensile Test Device

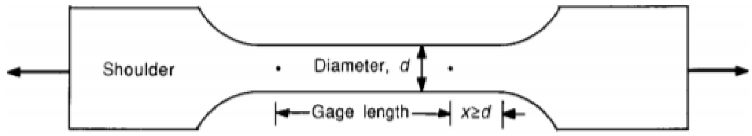


Figure 23 Typical tensile specimen

A material's tensile mechanical properties can be learned by tensile testing. These characteristics provide details like the material's failure point as well as traits like elastic modulus, strain, and yield strength. Table 2 displays the tensile test limits.

Table 2 Tensile test limits

Spoke	Yield Strength, MPa	Min 160
	Ultimate strength, MPa	Min 206
	Average %elongation	Min 2
Outside Flange	Yield Strength, MPa	Min 180
	Ultimate strength, MPa	Min 255
	Average %elongation	Min 7
Inside Flange	Yield Strength, MPa	Min 150
	Ultimate strength, MPa	Min 255
	Average %elongation	Min 7

The yield strength: The point of plastic deformation caused by stress is the yield strength. Extensometers are used in testing over a given gauge length to ascertain this. Devices that are mechanical clip on or video can be used in situations when non-contact is restricted, such as when testing at high temperatures. Samples are gathered from various tire parts, as shown in Figure 23.

Ultimate Tensile Strength (UTS): The UTS is the highest stress that a specimen can withstand when being tested. Depending on whether the specimen is brittle, ductile, or a combination of the two, this may not be the same as its breaking strength. Depending on the environment, such as extremely hot or cold temperatures, these material qualities can alter.

Ductility: Ductility is the term used to describe the lengthening of a tensile test. The percentage of elongation is calculated by dividing the largest gage length by the initial gage length (Saba et al.,2019) (Davis, 2004).

13° Impact Test

The technical drawing is used to confirm the vehicle load in the model. A +10% impact load or the vehicle's own weight are used to estimate the load. As shown in Figure 24, the device's computed weight unit is positioned on the impact test machine. After the test, the wheel surface is adjusted.

Figure 24 13° Impact Test

Filiform Corosion and Cass Test

Filiform corrosion is a type of corrosion that occurs on coated steel, aluminum, and magnesium surfaces. It causes the coating to separate from its metallic support due to surface corrosion of the underlying metal at the metal/coating interface. Filiform corrosion is mostly a surface corrosion that affects the surface look, with the underlying metal corroding only a few hundredths of a millimetre deep and having no effect on the mechanical resistance of the substrate.

Filiform corrosion occurs when lacquered surfaces have faults or weak areas. It spreads as filaments regardless of the coating's physical qualities, application method (liquid or thermal lacquering), or physical parameters. Sharp machined edges, scratches, tool-induced mechanical damage, as well as coating surface defects (thinning, microporosities, etc.) and water stagnation zones, are favored places for filiform corrosion to begin.

The direction of filament propagation is unpredictable and does not always coincide with the directions of extrusion or rolling. The filament traces can extend for many centimetres and are relatively stable. However, as illustrated in Figures 25 and 26, filaments never cross one other.

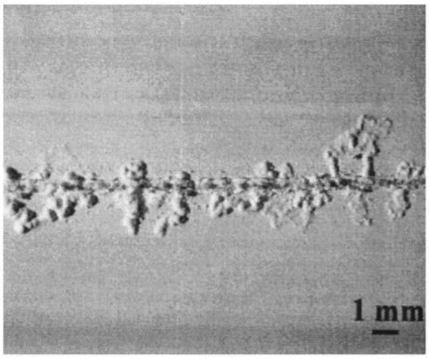


Figure 25 Filiform Corosion

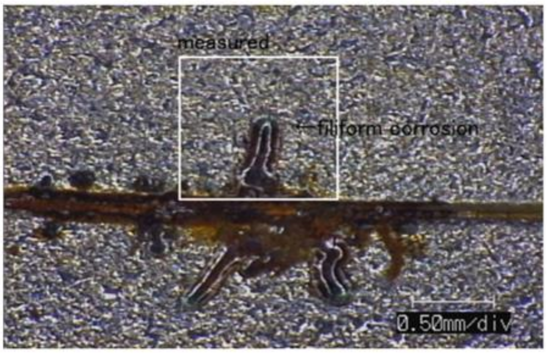


Figure 26 Appearance of Filiform Corosion Tracks

At the anode, the head of the filament, surface dissolution of the metal occurs

$$AL \rightarrow Al^{+3} + 3e^{-}$$

$$Al^{+3} + 3H_2O \rightarrow Al(OH)_3 + 3H^{+}$$

At the cathode, the head of the filament, surface dissolution of the metal occurs:

In neutral environment: $O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$

In acidic environment: $O_2 + 4H^{+} + 4e^{-} \rightarrow 2H_2O$

The main parameters are: alloy compositions; scalping of ingots and billets; heat treatments; the condition of the metal surface layer; relative humidity (RH); temperature; grinding; pickling; preliminary surface treatments. At the end of the test, filament length is measured. It should be maximum 2 mm.

A Copper Accelerated Salt Spray Test (CASS Test) is a test used to determine the resistance to corrosion of aluminum alloys. The cass test solvent is prepared according to customer specifications.

NaCl:50 g/l ± 5 g/l. (DI water -20 µS/cm)

$CuCl_2.2H_2O$: 0,268 g/lt, CH3COOH: 1 ml/lt (0,26 g/l ± 0,02 g/l), pH:3,0-3,1 (25°C)

The environment conditions: pH:3,1-3,3 (25°C), Temperature: 50 ± 2 °C, Pressure: 98 kPa ± 10 kPa.

After 24 hours, the test samples are taken to the lab for testing. They are stored in a laboratory at 18-28°C with a maximum relative humidity of 75 percent.

Deformation, cracking, lifting, and other effects on the paint around the scratch are perceived and recorded after the scratch.

The prepared solution is poured into the test device's solution tank. In the test device, the conditions listed above are created. The filament length is measured at the end of the test. It should be no more than 10 mm.

Water resistance Test

At 40 ±1 °C, test pieces are immersed in distilled or deionized water for at least 1/2 of their length. The test pieces are taken from the water at the end of the 240-hour immersion test and the water droplets on them are wiped away using a cloth. Within 10 minutes following the end of the test, the sample surfaces are evaluated for wrinkling, cracking, blistering, peeling, loss of brightness, and color change. Following the completion of the test, 100 squares are constructed in standard ambient conditions (23±2°C, 50±5 percent RH) in accordance with the standard, and adhesion tests are done using Nichiban tape after 10 minutes, 1 hour (maximum 2 hours), and 24 hours (maximum 26 hours).

Humidity Test

A constant humidity condensing (CH-KK) atmosphere is used for the humidity test. The test is carried out in a humidity cabinet for 240 hours at 40±3 degrees Celsius and 100% relative humidity. Wait 30 minutes at room temperature after the humidity test before performing the adhesion test.

Microstructure test

Microstructure can also be used to predict tool life or even the performance of a particular part, since it can be used to reveal specific properties, such as strength, ductility, corrosion resistance, and other conditions and properties. Firstly, samples were polished as shown in Figure 27. The goal of the surface polishing is to end up with a planar cross section of sample free from scratches or disturbed metal introduced by the cutting and sectioning.

This process is a step-wise process that can be broken into three loosely separate parts: grinding, coarse polishing, and final polishing. As shown in Figure 28 samples are analyzed by using microscopy.

Figure 27 Wheel sample

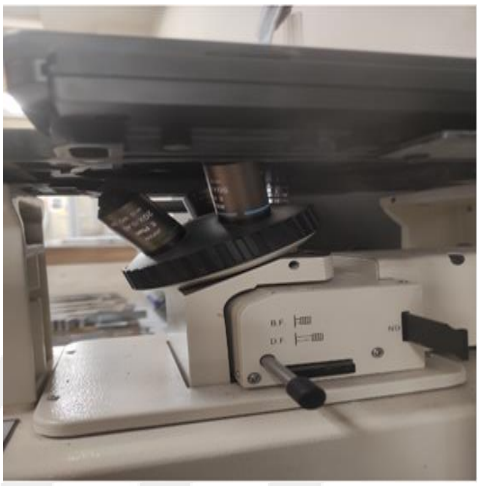


Figure 28 Micro structure test microscopy

After these kinds of tests, the experimental plan is formed to optimize the paint stripping process.

3.4 Determination of Optimum Paint Stripping Process Parameters

Another step is analysis of process parameters for paint stripping. The parameters affecting stripping process are temperature, time and sulfuric acid concentration. The experimental plan was formed by Using (Minitab20 full factorial design-response optimizer tool). Minimum and maximum values of these parameters are given in Table 1.

4. RESULTS AND DISCUSSION

4.1 Use of Lean Manufacturing System For Analysis of Scrap Ratio.

In the first stage of study, by using pareto chart scrap problems were analyzed. A Pareto chart is a bar chart in which the bars are ordered from highest frequency of occurrence to lowest frequency of occurrence. Figure 29 shows rank of the defects from largest to smallest in order to prioritize quality improvement efforts. As shown in Figure 29, main defects come from painting and casting processes.

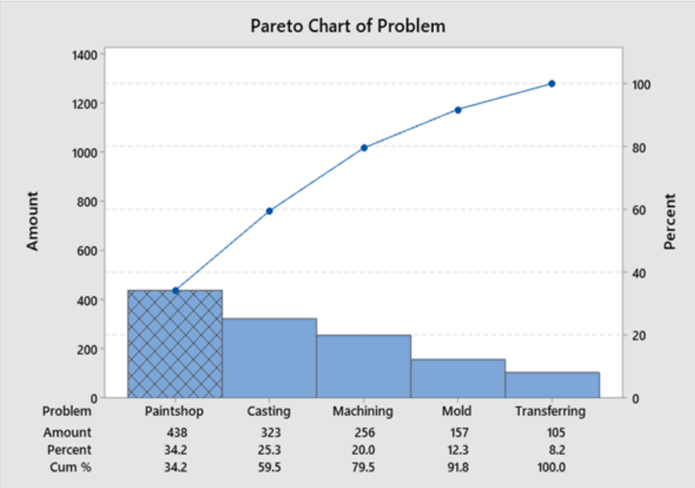


Figure 29 Pareto Chart of Problem

To increase the productivity, it is necessary to focus on these process steps. Cause and effect diagrams for painting and casting problems are shown in Figure 30 and Figure 31.

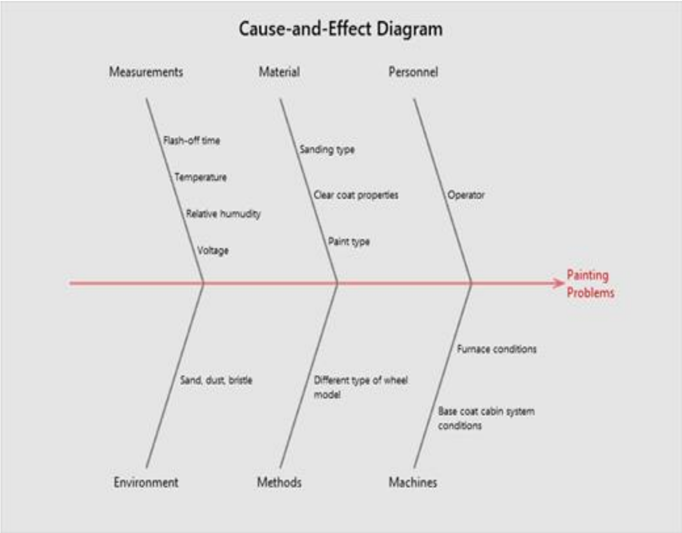


Figure 30 Cause-and-Effect Diagram- Painting problems

The main painting problems are related to painting system conditions. The conditions such as temperature and relative humidity affect quality of the process.

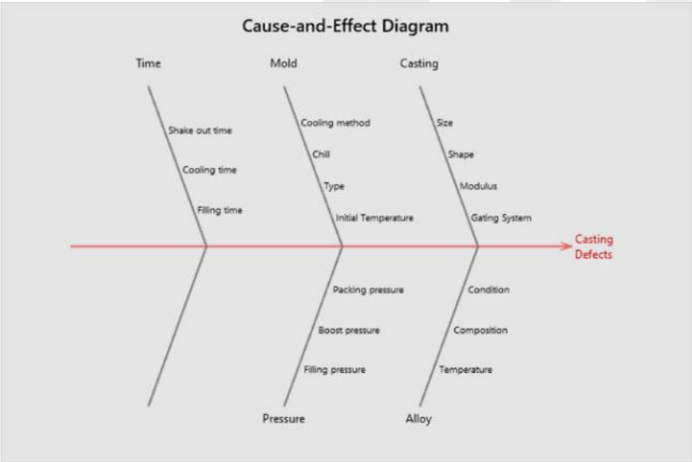


Figure 31 Cause and Effect Diagram-Casting Defects

The main casting problems are related to casting process parameters. In general, porosity is the main problem of this process.

4.2 Mechanical, Material and Paint Test Results

To reduce the scrap ratio, paint stripping process is applied to wheels which has defects on surface. After this process wheels are painted. As it is explained before, mechanical and material test results should be within acceptable limits. So, the experimental design with two types of wheels (diamond cut and cast surface wheels) and three types of painting (two different opaque and metallic paints) was performed. It is seen that test results are in acceptable ranges according to Table 2 and Table 3. As shown in Figure 32 Model-1 and Model-2 are opaques and Model-3 is metallic.

Diamond Cut Wheels

a b c

Figure 32 Diamond cut wheels a & b opaque c) metallic paint

For all models three different zone tests are performed.

The results for diamond cut wheels are shown in Table 3. There is no major difference from model to model. But some different values are seen according to zone. Hardness test, 13° impact test, adhesion test, water resistance, humidity test, 240h cass test results are acceptable after paint stripping process.

An interval plot shows a 95% confidence interval for the mean of each group. The interval plot represents the yield strength of wheels. Usually, the larger the sample size the smaller and more precise the confidence interval.

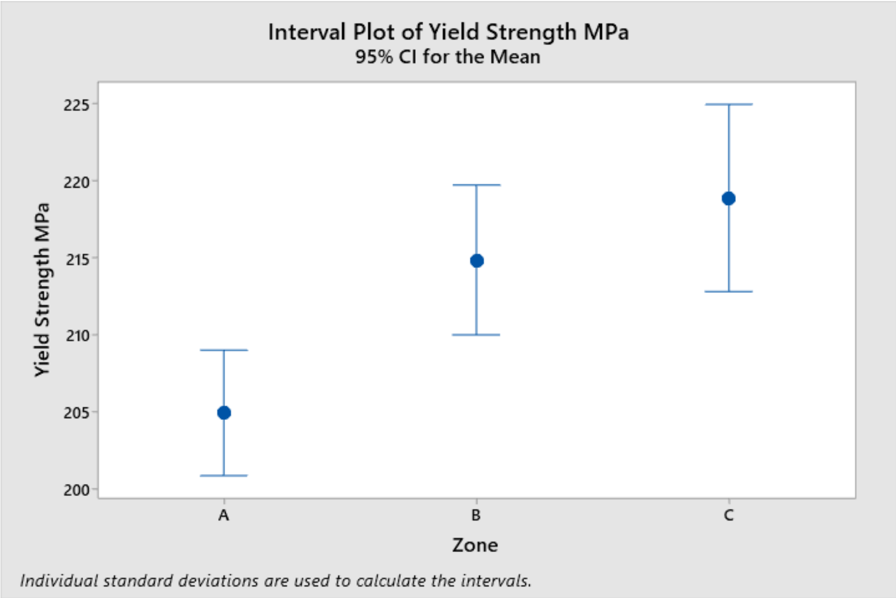


Figure 33 Interval plot of yield strength

In the Figure 33, the second and third intervals overlap with each other, but they do not overlap with the first interval. The mean of the first group could be significantly different than the means of the other two groups. In Figures 33, 34 and 35 yield strength, ultimate strength and elongation interval for each zone are shown.

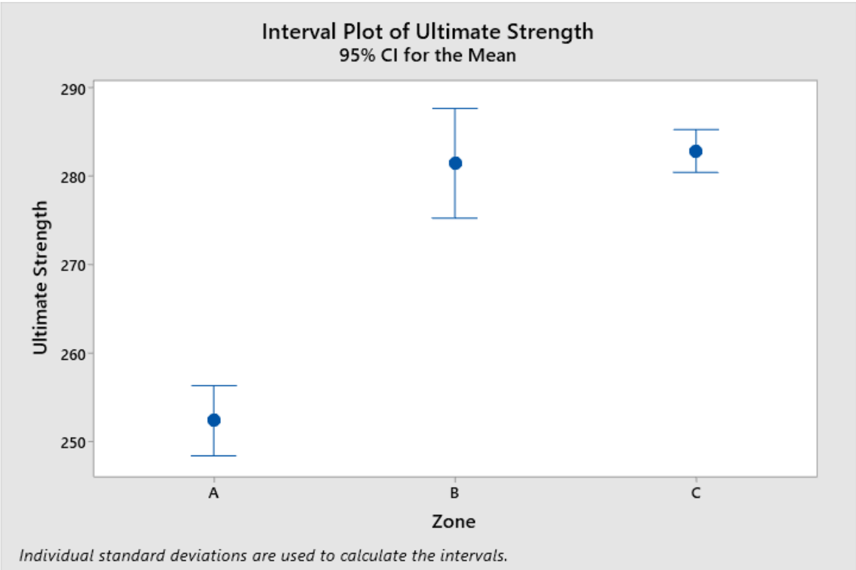


Figure 34 Interval plot of ultimate strength

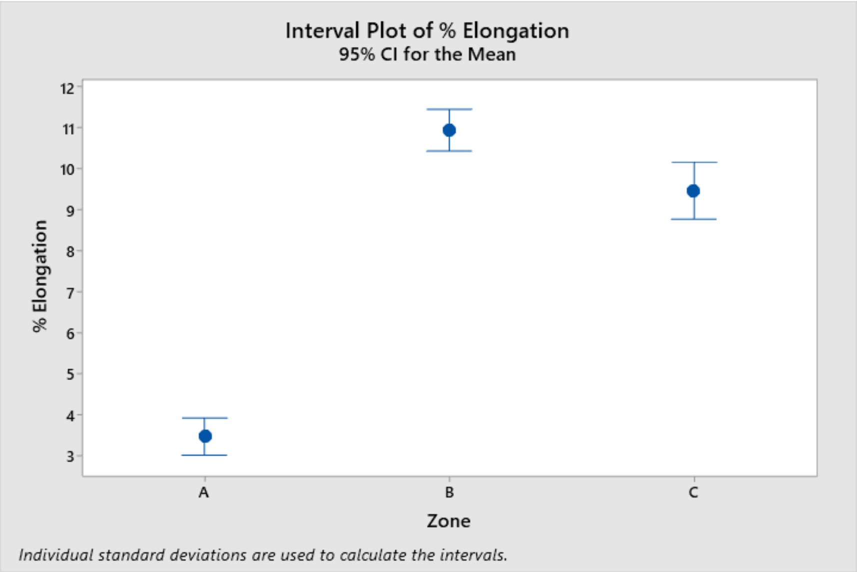


Figure 35 Interval plot of %elongation

Table 3 Results for diamond-cut wheels

Tests		Model-1	Model-2	Model-3
Spoke	Yield Strength, MPa (min160 MPa)	204,34	202,41	203,86
	Ultimate strength, MPa (min 206 MPa)	251,34	258,31	246,04
	Average %elongation (min %2)	3,41	4,99	2,77
Outside Flange	Yield Strength, MPa (min 180 MPa)	214,93	212,31	204,70
	Ultimate strength, MPa (min 255 MPa)	280,63	281,83	272,33
	Average %elongation (min %7)	10,95	11,16	11,20
Inside Flange	Yield Strength, MPa (150 MPa)	218,87	215,02	215,75
	Ultimate strength, MPa (min 255 MPa)	282,88	285,47	288,33
	Average %elongation (min %7)	9,43	9,36	12,20
Hardness Test		OK	OK	OK
13° impact test		OK	OK	OK
Dynamic fatique test		260K-OK	260K-OK	260-OK
Adhesion Test		OK	OK	OK
Impact Test		OK	OK	OK
Water resistance		OK	OK	OK
Humidity		OK	OK	OK
240h Cass Test		1,5	0,17	0,38

Cast-Surface Wheels

Same tests are done for cast surface wheels. As seen from the Table 4 the results can meet customer specifications. After paint stripping process the specifications are in the acceptable limits if they are compared with the values in Table 2. That means paint stripping process has no significant effect on wheels.

a

b

c

Figure 36 Cast surface wheels a&b opaque c) metallic

Table 4 Results for Cast Surface Wheels

Tests		Model-1	Model-2	Model-3
Spoke	Yield Strength, MPa (min160 MPa)	200,03	202,13	206,89
	Ultimate strength, MPa (min 206 MPa)	244,8	258,21	263,44
	Average %elongation (min %2)	3,14	3,87	5,02
Outside Flange	Yield Strength, MPa (min 180 MPa)	216,06	220,08	215,51
	Ultimate strength, MPa (min 255 MPa)	274,89	284,05	286,12
	Average %elongation (min %7)	7,65	9,65	9,50
Inside Flange	Yield Strength, MPa (min 150 MPa)	222,36	228,46	214,33
	Ultimate strength, MPa (min 255 MPa)	283,05	287,48	289,33
	Average %elongation (min %7)	8,43	6,96	10,92
Hardness Test		OK	OK	OK
13° impact test		OK	OK	OK
Dynamic fatique test		260K-OK	260K-OK	260K-OK
Adhesion Test		OK	OK	OK
Impact Test		OK	OK	OK
Water resistance		OK	OK	OK
Humidity		OK	OK	OK
240h Cass Test		0,50	0,42	1,0

The main issues, as indicated in Figure 29 are caused by painting and casting. Furthermore, porosity is one of the most significant casting flaws. As demonstrated in Figures 37 and 38, porosity problems on the surface are noticed at the end of the process.

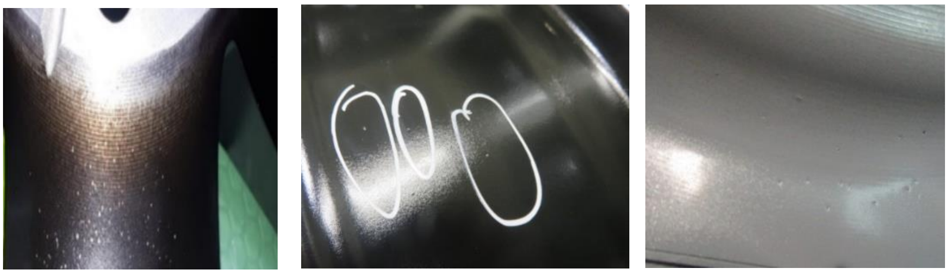


Figure 37 Porosity after paint stripping. Cast surface wheel

Figure 38 Porosity after paint stripping. – Diamond cut wheel

Table 5 Paint Stripping Process Test Parameters

StdOrder	RunOrder	CenterPt	Blocks	Temperature	Time	Concentration	StdOrder_1	RunOrder_1	Blocks_1	CenterPt_1	Porosity
1	1	1	1	80	20	96	1	1	1	1	0,33
4	2	1	1	80	25	98	2	2	1	1	0,27
2	3	1	1	85	25	96	3	3	1	1	0,67
3	4	1	1	85	20	98	4	4	1	1	0,75
6	5	1	2	80	25	96	5	5	1	1	0,62
7	6	1	2	80	20	98	6	6	1	1	0,54
5	7	1	2	85	20	96	7	7	1	1	0,47
8	8	1	2	85	25	98	8	8	1	1	0,83

After paint stripping process porosity value is checked with microstructure test. As shown in Table 5, porosity is selected as a response. Because of diamond machining limit on surface, diamond-cut wheels are painted as cast surface wheels without diamond machining process. That's why paint stripping process parameters are tested on cast-surface wheel. Figure 39 and Figure 40 show representative area of cast surface wheel samples that polished sample used for porosity analysis. For the microstructure test, cast surface wheels were used.

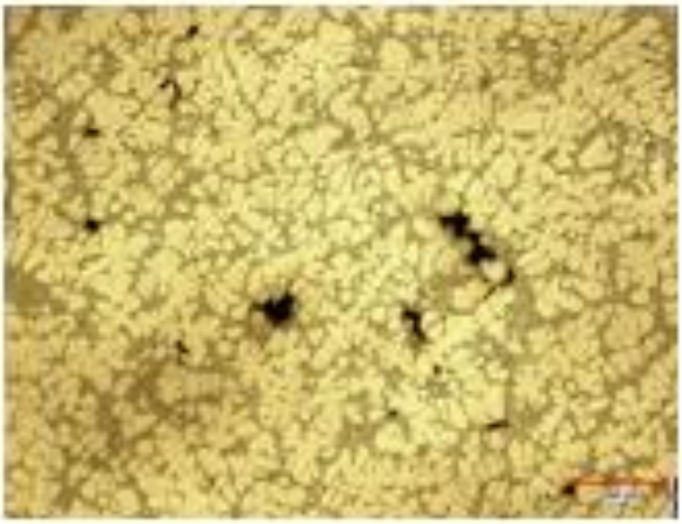


Figure 39 Cast Surface Wheel Porosity Results for Parameter, 80°C, 20 min, 98%, Porosity 0,54

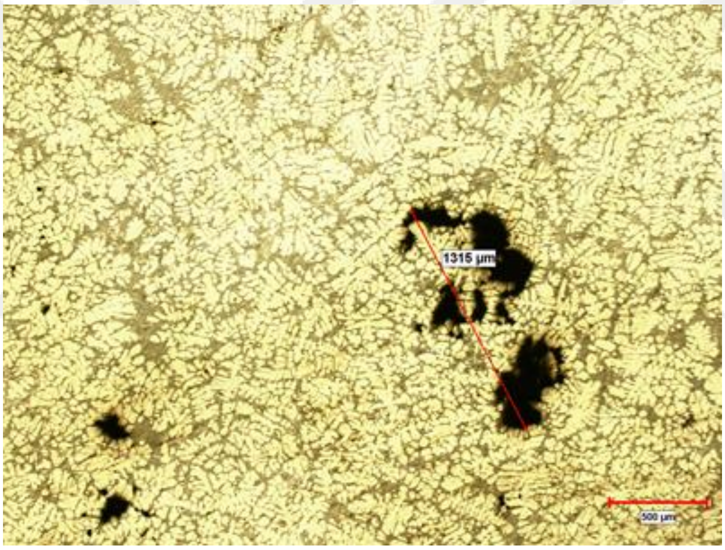


Figure 40 Cast Surface Wheel Porosity Results for Parameter, 85°C, 25 min, 98 %, Porosity 0,83

4.3 Determination of Optimum Paint Stripping Process Parameters

By using minitab full factorial design tool Coded coefficients are provided in Table 6. The p values of each individual component and factor pair provided in coded coefficients are larger than 0.05.
The size and direction of the relationship between a term and the response, which is the porosity ratio, are indicated by the effect. Temperature is a more important parameter, as listed in Figure 6. The variance inflation factor (VIF=1) The low multicollinearity of the factors is indicated by the numbers in this section. It's a desirable state. The standard error estimates the variability of a population's

multiple samples. The coefficient's standard error is always positive. The t-value displays the magnitude of the difference in comparison to the variance in the sample data. The p-value is calculated by Minitab using the t-value, which you may use to see if the coefficient is substantially different from 0. A p-value is a statistical metric used to test a hypothesis against actual facts. The likelihood of getting the observed results, given the null hypothesis is true, is measured by a p-value. The statistical significance of the observed difference increases as the p-value decreases. Table 6 illustrates this. The lower the temperature p-value, the stronger the statistical significance of the difference detected. Minitab calculates variables' effects and interactions. The absolute magnitude of the pair effect of time and concentration is greater than temperature, as seen in Table 6. It denotes a higher level of responsiveness.

Table 6 Coded Coefficient

Term	**Effect**	**Coef**	**SE Coef**	**t-Value**	**p-Value**	**VIF**
Constant		0,5600	0,0550	10,18	0,062	
Temperature	0,2400	0,1200	0,0550	2,18	0,274	1,00
Time	0,0750	0,0375	0,0550	0,68	0,619	1,00
Concentration	0,0750	0,0375	0,0550	0,68	0,619	1,00
Temperature*Time	0,0650	0,0325	0,0550	0,59	0,660	1,00
Temperature*Concentration	0,1450	0,0725	0,0550	1,32	0,413	1,00
Time*Concentration	-0,1700	-0,0850	0,0550	-1,55	0,366	1,00

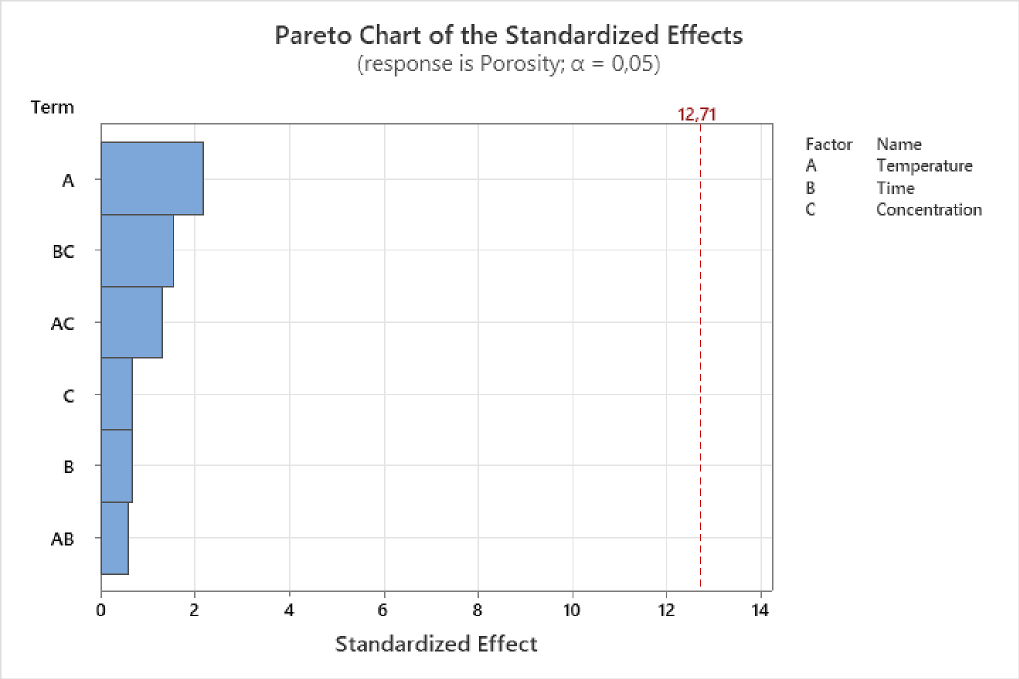


Figure 41 Pareto Chart of the Standardized Effects

Table 6 shows that the standardized coefficient with the biggest absolute value is temperature, followed by time*concentration. Temperature, followed by temperature*concentration, exhibits the greatest amount of fluctuation in Figure 40.

The pareto chart illustrates the effects of the three parameters on porosity. Temperature is the most effective factor. The absolute value of the effects is displayed on the Pareto chart. Figure 41 shows which effects are significant, however it is not clear whether effects raise or decrease the response.

A Pareto chart, as shown in Figure 40, determines the amount and significance of the effects. All three main effects are considerable, including temperature (A), time (B), and concentration (C).

Figure 42 shows the fitted means for each level of each categorical variable.

It is indicated that as the temperature rises from 80 to 85 degrees Celsius, the

mean porosity rises from 0.44 to 0.67. Temperature variability had the greatest increase. Temperature, time, and concentration all increase porosity considerably. Because the lines are not horizontal, main effects exist for all of these factors.

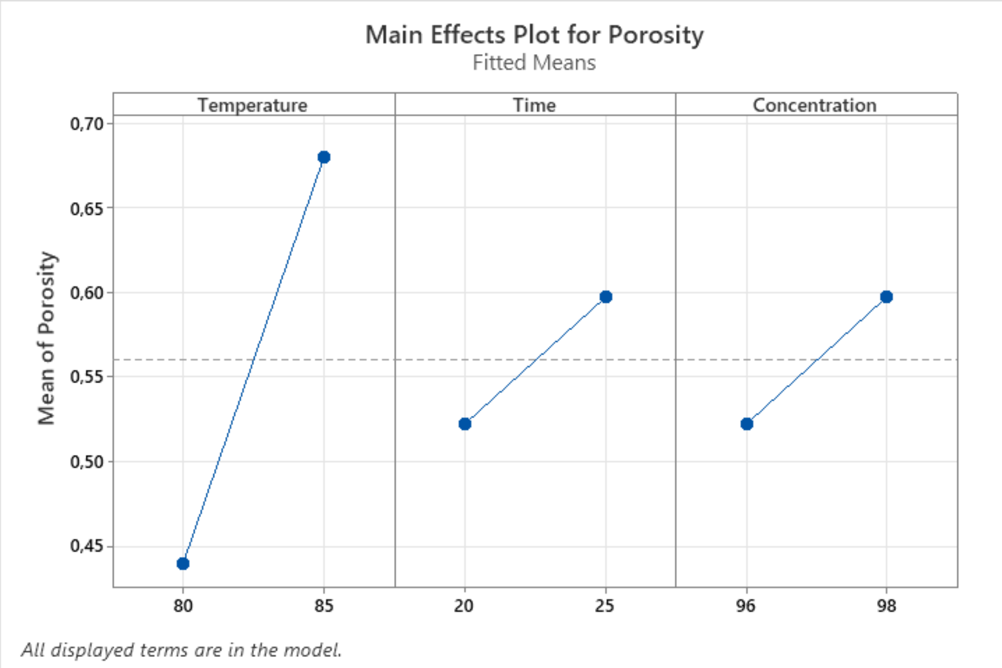


Figure 42 Main effects for porosity

Figure 43 depicts the interaction between each pair of parameters. Because the lines are not in parallel in this plot, it signifies that the link between porosity value and each element is dependent on the setting of another factor. Figure 43 depicts the temperature and time interaction, demonstrating that the influence of time on porosity is stronger for 25 minutes than for 20 minutes. The link between porosity value and concentration is time dependent. Also temperature and concentration lines are not parallel. It is express that the relationship between time and concentration depends on the value of temperature. As shown in Figure 43, the influence of concentration 98 is stronger than 96.

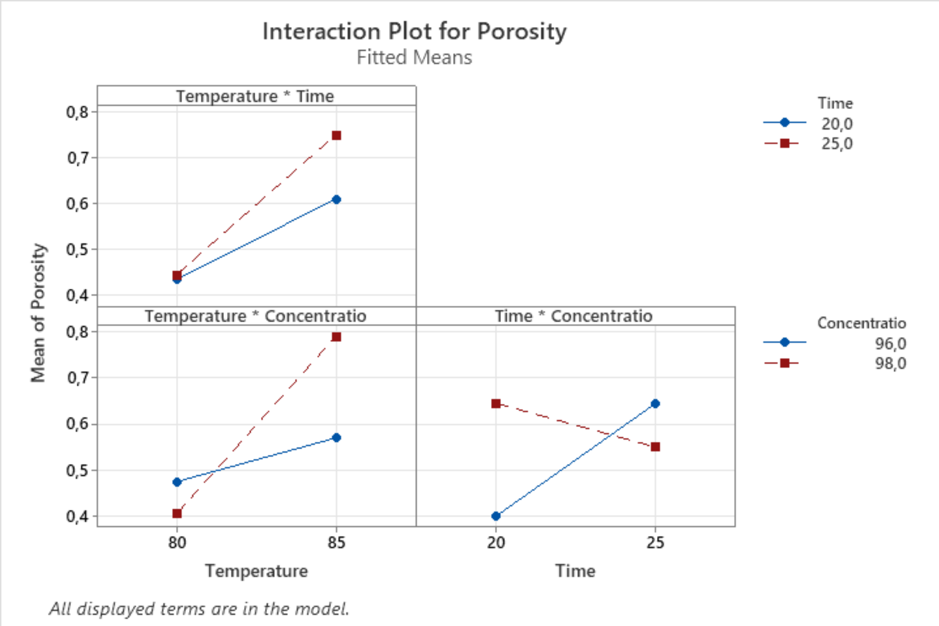


Figure 43 Interaction Plot for Porosity

Table 7 shows the optimal circumstances based on the results. The weighted geometric mean of the individual desirability for the responses is the composite one. Minitab determines optimal variable settings by maximizing the composite desirability. The composite desirability (0,901786) is close to one, indicating that the settings appear to produce favorable results across all respondents.

Table 7 Optimum Conditions

Solution	**Temperature**	**Time**	**Acid Concentration, %**	**Porosity Fit**	**Composite Desirability**
1	80	25	98	0,325	0,9018

A confidence interval is the mean of the estimate proposed plus and minus the variation in that estimate. A confidence interval is a set of values generated from sample statistics that are likely to include the value of an unknown population parameter. The mean porosity is 0.325 as reported in Table 8, and the range of expected values for a single future value is -2,382 to 3,032.

Because forecasting a single answer value is less certain than predicting the mean response value, the prediction interval is always wider than the matching confidence interval.

Table 8 Confidence interval and prediction interval of porosity

Response	Fit	SE Fit	95% CI	95% PI
Porosity	0,325	0,146	(-1,524; 2,174)	(-2,382; 3,032)

The overall response is 0,325, as indicated in Table 8. For given values of the predictors, the fitted values are point estimations of the parameter.

For the supplied variable settings, the standard error of the fit (SE fit) assesses the variation in the estimated mean response. The standard error of the fit is 0,146. It is used to calculate the confidence interval for the mean answer.

These confidence intervals (CI) are a set of numbers that are most likely to contain the mean response for a population with the observed values of the model's variables.

Because there is more uncertainty in forecasting a single response vs the mean response, the prediction interval (PI) is always wider than the confidence interval. As shown in Table 8, the confidence interval is between -1,524 and 2.174. The prediction interval is between -2.385 and 3.032.

The graph of optimization the effect of each component (columns) on the replies is depicted in Figure 44. The current factor settings are represented by the vertical red lines on the graph. The current factor level settings are shown by the numbers at the top of each column (in red). The responses for the current factor level are represented by the horizontal blue lines and numbers.

The response optimizer tool is used to minimize the porosity effect, as shown in Figure 44. The response is minimal when the sulfuric acid concentration is 98 percent, the time is 25 minutes, and the temperature is 80 degrees Celsius.

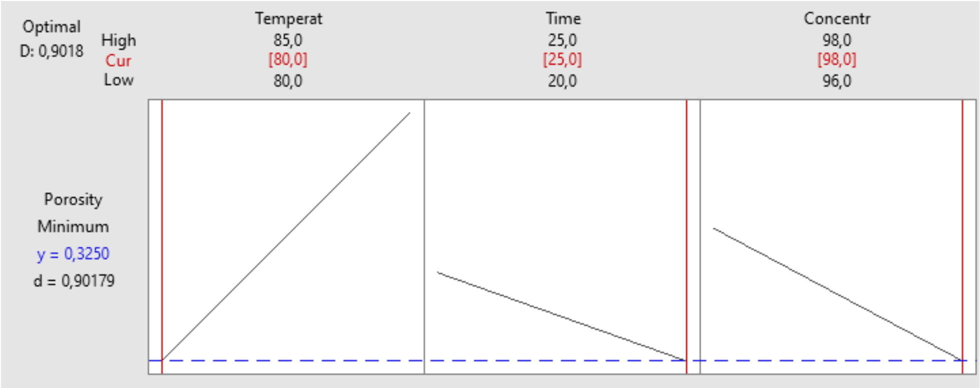


Figure 44 Response optimizer results

5. CONCLUSIONS

In the first part, method of producing wheels was explained in this study. For this reason lean manufacturing system was used for analysis of scrap ratio (Fish-bone diagram, pareto chart). The aluminum alloy wheel manufacturing process is divided into three stages: casting, machining, and painting. The molten metal quality is frequently excellent, with low amounts of impurities and hydrogen gas. Machining is the process through which a substance is cut to the required shape. In this procedure, the desired tire cross-section shape is constructed, as well as the drilling of the cap, wheel bolt, and valve of the wheels produced by the low pressure casting method. The painting process serves two purposes. The first is to protect the substrate materials, and the second is to improve the aesthetic.

Problems that may arise in these processes may result in inefficient output. The paint stripping method can recycle wheels that are considered waste due to flaws on the coating surface. It is critical to reduce the scrap ratio in order to boost productivity. The lean manufacturing method focuses on minimizing waste and increasing customer satisfaction. The scrap ratio is calculated using the pareto chart approach. The reasons for scraps are discussed using a fish-bone illustration to improve the scrap ratio.

Paint stripping in the aluminum wheel industry has typically meant removing chemical paint from the surface. It's vital to investigate the wheels that have been stripped of their color. It is vital that the paint stripped wheels go through this phase due to complications with the painting process. During the paint peeling process, there are significant technical, environmental, and/or safety limitations. Methylene chloride and concentrated sulfuric acid are the two most used techniques for stripping paint. In this study, the method of concentrated hot sulfuric acid was chosen. The results of mechanical and material tests such as the Brinell hardness test, scratch test, tensile strength, and filiform corrosion for cast and diamond –cut wheels were then analyzed.

Mechanical, material, and paint test results are required to see the effect of the paint stripping method. For these tests, diamond cut and cast surface wheels, as well as metallic and opac painting for each type of wheel, were used. There is no significant difference in the test results between cast surface and diamond cut wheels.

	Cast Surface Wheels		Diamond Cut Wheels	
	Min	Max	Min	Max
Yield Strength, MPa	200,03	228,46	202,41	218,87
Ultimate Strength, MPa	244,8	289,33	246,04	288,33
Elongation, %	3,14	10,92	3,41	12,20

It is seen that results are in acceptable ranges according to customer specifications. After paint stripping process wheels are analyzed. It was seen that paint stripping process can be used.

The second phase of the study focused on the flaws (runs or sags, foreign matter, stain) on the wheel before and after the paint stripping procedure in order to increase efficiency. Cast surface and diamond cut wheels were used and it was seen that porosity is the most important factor causing inadequacy in the paint stripping process. As a precaution the paint striping process' parameters can be tuned to reduce porosity. As a result, it was decided to improve the paint removal process efficiency. The optimum conditions were 80°C for temperature, 25 minutes for time, and 98 percent for sulfuric acid concentration, according to the data. The most effective component was revealed to be temperature. Temperature and concentration interactions, as well as time and concentration interactions, remained largely consistent. The link between porosity value and concentration was affected by the time it takes to complete the procedure.

As a consequence, if the paint stripping technique is carried out under optimum conditions, the scrap ratio for wheels will be decreased, resulting in a gain in production efficiency.

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