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VAN YUZUNCU YIL UNIVERSITY  
INSTITUTE OF NATURAL AND APPLIED SCIENCES  
DEPARTMENT OF CIVIL ENGINEERING

**EFFECT OF COLD JOINT ON COMPRESSIVE AND TENSILE STRENGTH OF  
CONCRETE**

M.Sc. THESIS

PREPARED BY: Quraish Qusay ALI  
SUPERVISOR: Assoc. Prof. Dr. Barış ERDİL  
CO- SUPERVISOR: Dr Taha Mohammed JASSAM

VAN-2020



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## ACCEPTANCE and APPROVAL PAGE

This thesis entitled “**EFFECT OF COLD JOINT ON COMPRESSIVE AND TENSILE STRENGTH OF CONCRETE**” presented by Quraish Qusay ALI under supervision of Assoc. Prof. Dr. Barış ERDİL in the Department of Civil Engineering has been accepted as a M. Sc. thesis according to Legislations of Graduate Higher Education on 25/10/2020 with unanimity of votes members of jury.

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## THESIS STATEMENT

All information presented in the thesis obtained in the frame of ethical behavior and academic rules. In addition, all kinds of information that does not belong to me have been cited appropriately in the thesis prepared by the thesis writing rules.

Signature

Quraish Qusay ALI



## ABSTRACT

### EFFECT OF COLD JOINT ON COMPRESSIVE AND TENSILE STRENGTH OF CONCRETE

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M.Sc. Thesis, Civil Engineering Department  
Supervisor: Assoc. Prof. Dr. Barış ERDİL  
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This study aims to understand the effect of tensile and compressive stress on concrete with cold joint problem. A series of tests were designed in the context of this study. 4 different concrete grades (10, 20, 25, 30MPa) were selected and concrete grades demonstrate the very low grade, low grade, minimum grade according to Turkish Earthquake Code 2007 (TEC2007), minimum grade according to Turkish Earthquake Code 2018 (TEC2018) and normal grade concrete. In addition to the concrete grades, cold joint angle is also a parameter to be investigated. Zero angle will be the control angle since in this case the cold joint will be under fully compression. Besides, 20,45,65 and 90 degrees will be studies to understand the effect of cold joint angle on tensile and compressive strength capacity of the concrete. The results showed that samples with a resistance of 20, 25 and 30 MPa that have a cold joint with a zero angle have results close to the standard samples. Samples that have a cold joint at an angle of 90 with the same resistance had high results but less than the angle of zero. Samples with a cold joint at angle of 20 and 45 were ranked third in terms of resistance after samples that had a cold joint with angle of 0 and 90 and had similar behavior and close results. While samples with cold joint 65 were very weak. As for samples that have compressive strength 10, there is no effect of cold joint due to weakness of concrete. As for the effect of cold joint on tensile strength of samples with resistance 20°, 25° and 30°, samples at angle of 0°, 20°, 45° and 65° gave close results, however samples at angle of 90° gave the lowest resistance.

**Keywords:** Angle of concrete joint, cold joint, compressive strength, tensile strength.



## ÖZET

### SOĞUK DERZİN BETONUN BASINÇ VE ÇEKME DAYANIMINA ETKİSİ

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Bu çalışma betonlarda soğuk derz probleminin çekme ve basınç dayanımlarına olan etkisi anlamayı amaçlamaktadır. Çalışma kapsamında seri deneyler tasarlanmıştır. Dört farklı beton dayanımı (10, 20, 25, 30 MPa) seçilmiştir. Bu beton dayanımları çok düşük dayanım, 2007 Deprem Yönetmeliği'nde belirtilen minimum dayanım, 2018 Deprem Yönetmeliği'nde belirtilen minimum dayanımı ve nispeten yüksek dayanımı temsil etmektedir. Beton dayanımlarına ilave olarak soğuk derz açısı da incelenecek diğer parametredir. Soğuk derz açısının sıfır derece olması durumunda soğuk derz tamamen basınç altında olacağı için control numunesi olarak da değerlendirilebilir. İlave olarak soğuk derzler 20, 45, 65 ve 90 derece olacak şekilde planlanarak açıların çekme ve basınç dayanımına etkisi araştırılmıştır. Deney sonuçlarından 20, 25 ve 30 MPa numunelerde sıfır derecenin soğuk derz olmayan control numuneleri ile benzer dayanımlara sahip olduğu görülmüştür. 90 derece soğuk derz olması durumunda basınç dayanımı sıfır dereceden bir miktar düşük çıkmıştır. 20 ve 45 derece soğuk derz olması durumunda basınç dayanımında bir miktar düşüş görülmüş ise de sonuçların 0 ve 90 derece ile benzerlik gösterdiği gözlenmiştir. Basınç dayanımı noktasında en kötü davranış 65 derece soğuk derz olması durumunda gözlenmiştir. 10 MPa dayanıma sahip numuneler çok düşük dayanıma sahip olduklarından soğuk derz farkı çok hissedilmemiştir. Çekme dayanımı hususunda ise 20, 25 ve 30 MPa'lık numunelerde 0, 20, 45 ve 65 derece soğuk derzin etkisi pek görülmemişken 90 derece soğuk derz olması durumunda en düşük dayanım elde edilmiştir.

**Anahtar Kelimeler:** Soğuk derz, beton derzi, basınç dayanımı, çekme dayanımı.



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2020

Quraish Qusay ALI



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## SYMBOLS AND ABBREVIATIONS

Some symbols and abbreviations used in this study are presented below, along with Descriptions.

<b>Symbols</b>	<b>Description</b>
<b>kN</b>	Kilo-Newton
<b>MPa</b>	Mega Pascal
<b>cm</b>	Centimeter
<b>mm</b>	Millimeters
<b>μm</b>	Micrometer
<b>°C</b>	Degree Celcius
<b>kg/m<sup>3</sup></b>	Kilogram/cubic meter
<b>w/c</b>	Water/cement ratio
<b>S</b>	Standard
<b>C</b>	Mix strength
<b>P</b>	Pattern
<b>lt</b>	Liter
<b>ρ</b>	Density
<b>σc</b>	Compressive stress, N/mm <sup>2</sup>
<b>P</b>	Maximum load, N
<b>A</b>	Cross section area mm <sup>2</sup>
<b>T</b>	Splitting tensile strength, MPa
<b>D</b>	Diameter of the specimen, mm
<b>L</b>	Length of the specimen, mm

**Abbreviations****Description**

ACI	American Concrete Institute
ASTM	American society for testing and materials
Al <sub>2</sub> O <sub>3</sub>	Aluminum oxide
CaO	Calcium oxide
GGBFS	Ground granulated blast furnace slag
LVDs	Low Voltage Differential Signaling
LOI	Loss on ignition
OPC	Ordinary Portland cement
CEM I	Portland Cement

# 1. INTRODUCTION

## 1.1 General

The more important reason for concrete used in structures is because of its abundance in nature, high strength and durability, low cost, process ability, fire resistance, environmental friendliness, engineering features that enable the construction of aesthetic structures and many more features. Therefore, the cement production is constantly increasing, as the global cement production in 1995 was 1.39 billion, while the global cement production in 2019 reached (4.2) billion tons, which indicates the extent of construction growth and the need for cement (Ünsal and Şen, 2008).

Although the concrete is fast to construct, low in cost, long life and durable, there are advantages and disadvantages to this material. For example, when concrete is strong and durable over time, high and low temperatures to the point of freezing cause the concrete to crack and expose the concrete to water, allowing water to seep through the cracks and cause damage to the concrete (Rathi and Kolase, 2013).

There have many problems in concrete due to a misunderstanding of its properties. The most important of which is the environmental conditions and its poor preparation. One of the wrong applications of concrete is that it is not brought to the construction site in the appropriate form and conditions, it is not properly placed in the casting area, it is not pressed with a vibrator, it is not subject to proper finishing, and it is not carrying out the necessary processing to it. As a result, there are problems in both strength and durability. Since concrete is a composite material, it is one that is more affected by the stages of production, transportation, and application compared to other building materials. In order to obtain the required performance in concrete, the properties of the concrete and the factors affecting it must be well known, examined and actions taken accordingly (Engin, 2019).

In a building, concrete formwork cannot be completed at one time especially if the workload is very large. In such a case, cold joint formation is mandatory, and it is a manufacturing defect, occurring in concrete poured on top of each other or side by side at different times. When the second layer is poured onto or next to an existing old

concrete, or at least immovable concrete, the two concrete will not stick together. A capillary crack forms in the form of a crack between two concrete, which is called a cold joint (Ölmez, 2019). There is another type of occasional problem that occurs during work, such as pouring concrete by hand due to delay of concrete conveyor, concrete pump failure, mold burst, etc. After the concrete begins to harden or completely harden, by continuing the concrete pouring process in the lift sections, joints called cold spacers and breaks are formed between the two layers (Tuğrul, 2010).

Some factors that affect cold joints are the angle of the joint and the roughness of the surface and the use of additives to improve the cohesion between the concrete layers. In this study, the focus was on changing the angle of the joint and knowing the extent of the impact on the tensile and compressive resistance without any additions or changes in the face of the concrete surface.

## **1.2.Cold Joint**

### **1.2.1. Cold joint definition**

Cold joint represents a weak place in the concrete body due to not pouring concrete simultaneously. It is formed when the first layer of concrete hardens before adding the next layer so that no overlap occurs between the two batches. Cold joints sometimes form due to delay and sudden interruption, and it may happen due to the end of the day and stop work, but it may get from poor cohesion between the components of the mixture. To prevent the occurrence of cold joints in other buildings and structures, concrete must be poured in layers and using vibrators to mix the previous and next layers. Pouring of concrete should start at the corners and then go to the center. When casting slab, it is necessary to place concrete next to the previous batch and not to be dumped in the form of a mound. On sloping places, the work starts from the bottom onwards. In hot climates, it is sometimes preferable to use a retarding admixture to slow down the setting time (Illangakoon, 2009).

Cold joint or construction joint for concrete is of importance in structural engineering to maintain a structure. Cold joint, means put up concrete on the concrete that has already been created and the time between the first batch and the next one is at

least one day. There are many reasons for having a construction joint. One reason is that one can only place so much concrete in a day. Another reason might be that it is not logistically possible to place the additional concrete until one ties rebar for the next placement. Perhaps, one could not tie that rebar until the first placement was made. The abutment back wall had to be placed before they could get set up for the work above it. The construction joint may be a weak space, but not always. If there is a pre-preparation for the joint to connect it later, structurally it is not considered a weak space. The surface should be incomplete and rough so that the concrete that is mechanically added bonds with this surface. When the bar is involved then cold joint may not be considered as a weak point.

The place of the cold joint is also important. One would not want to have a construction joint at the mid-span of a bridge girder, for example. An example of bridge girders is given in (Figure 1.1). These girders are partially in tension and partially in compression. Even with the internal rebar and strands, it is likely to have cracking at a construction joint; therefore, it should be avoided (Jatheeshan.et al, 2010).



Figure1.1. An example of a bridge girder (Dana M Dietz 2017).

### 1.2.2. Effects of a concrete cold joint

Cold joints are a type of crack in concrete as it hardens. These joints do not create holes in the ground, but rather cracks that may not contain an appreciable void framework. The cold joint is normally linear, strongly connected, and bonded. There is a possibility of a slight hollow space of concrete where the mortar is not completely compacted, as in most concrete pouring. This small gap will contribute to the creation of cracks in the future. Generally, cold joints do not cause any structural issues when the joint is in compressive (Ölmez, 2019).

### 1.2.3. Cold joints treatment

The risk of moisture penetration into the concrete portion is a more severe issue associated with a cold joint. If the water is collected in the joint, it may contribute to the corrosion of the steel. (Figure 1.2) indicates a cold joint in the support wall, however if a cold joint is created due to inevitable factors, in order to handle it, the following steps is adopted.

1. When concrete is plastic

If the concrete is so green that it can be cleaned manually and if the vibrators can permeate the face of concrete without any difficulty, fresh concrete can be mounted directly on the old floor.

2. When the cold joint is a bit hardened

In the event that the concrete has hardened it becomes a plastic further than the liquid condition, but can still be quickly removed with a gentle hand pick, the surface can be firmly ribbed and the loose concrete can be totally withdrawn without damaging the majority of the concrete in depth. A rich mortar layer of 12 mm thickness is mounted on a cold joint, fresh concrete is then mounted on a mortar layer and the joint is extensively and consistently vibrated, pushing the vibrator deep into the old concrete layer.

3. If the cold joint is hardened

In the event that the concrete at the joint has become so solid that it cannot be remolded and that the mortar or slurry does not lift amid the strong, shaking, the

joint must be left for at least 12–24 hours. It is then handled as a normal building joint after the concrete has been cut to the appropriate form and the surface is primed (Tuğrul, 2010).



Figure 1.2. Cold joint on wall.

#### 1.2.4. Preventing cold joint

In order to prevent breaks that may occur, a formwork layout must be made in advance. In other words, necessary precautions must be taken around the casting area of the construction site in order to prevent stoppage of casting work, and adequate number and quality of crew and equipment must be provided. Concrete formwork must be completed properly. Consideration must be given to the efficiency of the concrete plants and the transportation of concrete to the construction site. The order of the amount of concrete should be given correctly, and it should not be forgotten that a cold joint will be formed in a period of time after placing the new order. (Rathi and Kolase, 2013).

#### 1.2.5. Aims and objectives of the thesis

In a reinforced concrete, cold joint usually develops at the concrete layer of different ages. It is mostly inevitable because concrete cannot be casted in a single day. Concrete casted in different days creates a weak layer at the connection layers. That weak connection of concrete is called cold joint. Mostly cold joints are under

compressive and this action increases the friction between the layers. However, in bending action tensile stresses develop in the member. Concrete is weak in tension and further weakening from cold joint may affect the compressive strength and bending strength of the member. Recalling that column experience high bending moments during an earthquake, as in (Figure 1.3) they need to reserve their compressive and bending strength during the seismic action.

The objective of the research is to achieve the best shape of the cold joint so that it can obtain the best compressive resistance to the concrete and tensile strength also by changing the shape of the joint according to the measurement of the angle of the slope.



Figure 1.3. Cold joint in a column (Picture from Erbil City 2019).

## 2. LITERATURE REVIEW

Joints in concrete construction are the joints of construction, expansion, contraction and insulation that can be classified for each joint with specific use, benefits and harms. The research topic is concerned with cold joints, and in this chapter literature review is discussed.

Rao and Kishen (1993) studied the effect of cold joint according to the concrete size. First, prism molds of different sizes were prepared, and then half of the molds were poured with fresh concrete with the same mixing ratio, prepared in one go. After two days, the remaining half of the molds were filled with fresh concrete in the same mixing ratio and samples were prepared. Then bending strength test was done on these samples. According to the results of the study, the authors stated that reinforcements should be placed between the concrete that creates cold joints. If the sample size increases, the overall load capability increases and the flexural capacity of the cold jointed concrete decreases with time.

Direct tensile strength is influenced by different factors. Ribeiro et. al. (2001) analyzed the effect of relative humidity on the concrete surface of joints in case of concrete hardening and setting and treatment methods for cold joint. The results showed a decrease in joint efficiency with continuous exposure time, so the upper layer must be compressed before the initial setting time of the concrete in the lower layer. Also, wet treatment of the surface of the lower layer is necessary to prevent early hardening. The aggregate must also be treated in the cold joint, i.e. the surface of the lower layer is roughened, and the mortar layer is not reliable because it is not sufficient to give great tensile strength (Ribeiro et al, 2001).

They conducted experiments to study the effect of the cold joint at the transverse beams interface to determine the fracture characteristics. Simple support beams under three points of bending and different compressive strength of concrete were utilized. The results showed that the fracture energy decreases with increasing the difference between the compressive strength of the material on both sides of the interface. It has been shown that the interface samples have the same effect with the size of the intact

samples and the nominal force-to-volume regression on the logarithmic diagram  $1/2$  shows the applicability of linear elastic fracture mechanics (Kishen & Rao et al, 2007).

Pedro and Eduardo (2010) studied the degree of different roughness of cold joint. They investigated the effect of shrinkage and different stiffness properties on shear strength. This different rough forming technique has been applied within the scope of the study. . The load transfer mechanism at the concrete-to concrete interface is due to cohesion, friction and dowel action However, since all these design expressions are empirically based, dowel action is implicitly considered in cohesion and friction terms. Different shrinkage behavior causes extra stresses in the concrete-concrete interface. This situation is created in 28 days, 56 days and 84 days after the first part of the samples is poured for inspection, new concrete was poured and a cold joint was created. Also some of these samples kept in the laboratory, some of them are cured in the external environment to investigate the effect of curing. By forming a cold joint between concretes of different strengths, the effect of strength difference on shear strength was also investigated. In the results, it was possible to obtain 2D profiles of the surface texture and to compute texture parameters. According to the results of the experiments, it is recommended that poured concrete is not taken smaller than Young's modulus value.

Joints are usually the weak parts. In these parts, tensile strength of the concrete element in tension and bending action is less than for the concrete poured as a whole i.e., a homogeneous concrete. In addition, the carrier element is more easily affected by these parts due to its environmental effects. For this reason, a strong connection should be provided between the concrete layers to be added. In fact, cold joints are created in almost all buildings due to the fact that concrete is not poured at once. For example, it is known in advance that such joints and discontinuities will occur between column and beam concretes poured at different times, floor concretes or concretes of the foundation and the structural elements that will come on it. It is preferable to pour the column and beam concretes together to reduce the joints that may occur in this type. Structural elements should be constructed by taking care this type of problems and, if possible, by pouring the columns, beams and floor concretes together as a whole. If necessary, for example, due to the large concrete casting area, etc., the casting process will not be finished and the joint will have to be left, concrete casting should not be cut in a random

place, and the joints should be created in accordance with the technique (Figure 2.1) (Tuğrul, 2010).



Figure 2.1. Irregular cold joint.

Many causes and various factors ultimately lead to the formation of the cold joint. Rathi and Kolase (2013) studied one of the problems, which is the inappropriate pouring sequence where sugar used a retard factor. To investigate this, a concrete with a strength of C25 was used and three experiments were conducted for stained concrete, stained concrete with inhibitor agent and natural concrete. The results showed that the tensile, bending and compressive strength of the three types of concrete are that the stained concrete with retard factor gave well strength compared to other types in the level of horizontal failure (Rathi and Kolase, 2013).

In the cold joint work done by the company (Lion Corporation), after the first half of the mold was poured fresh concrete, after 72 hours, the second half of the molds was filled with fresh concrete with the same mixing ratio. The bending test was carried out on the prism sample with dimensions of 150x150x600 mm and basic samples with dimensions of 100x140 mm were taken from the concrete that formed a cold joint for the carbonation test. Samples used in carbonation were kept at different temperatures

and environments for 4 weeks. Carbonation of cold joint samples was compared to carbonation of normal concrete. As a result, as the time increases, the bending strength of the concrete formed decreases in the bending test performed on the prism samples, and according to the results of the carbonation experiment, the amount of carbonation formed in the cold joint is higher than the normal concrete carbonation amount (Lion, 2014).

The effect of water permeability on the cold joint was studied through an analytical model based on the concept of REV (Representative Element Size). OPC (Ordinary Portland Cement) concrete samples containing cold joint were produced. The curing time for samples was 91 days and then WPT (water permeability test) was performed. Cylindrical samples with a water to binder ratio of 0.6 and 40 % GGBFS (Granulated Ground Blast Furnace Slag) mixing with concrete were used. It was found that by replacing GGBFS in the concrete containing a cold joint, the water drainage decreased by 14.1% which was 10.9% for and concrete that does not contain. The increase in water permeability in normal concrete containing cold joint decreases by 47.9%. Whereas, in concrete with GGBFS the ratio was 27.1%. The results of the analysis according to the REV technique were good as the numerical results were reasonably consistent with the experiment with a ratio  $0.98\% \approx 14.93$  and  $2.39 \sim 12.97$  for the difference between samples without joints and samples containing cold joints, respectively (Choi et. al, 2015).

Cold joints and their effect on concrete strength were studied by conducting laboratory experiments and a constitutive model that explains and simulates the behavior of concrete over time under loads and without the existence of any load. Concrete cylinders were used to make samples. The results showed that samples that contain cold horizontal joints when applying compressive strength do not show any strength loss. Samples containing a cold joint with an oblique angle after exposure to compressive force, and the vertical joint that is subjected to indirect tensile force gave a large loss of resistance amounting to (30% and 42%), respectively. The value was greater in the case of the period of joint formation and early ages life of the sample (Torres, 2016).

The study conducted by Kadyrov and Yazıcıoğlu (2016), includes the effects of cold joint on the compressive, flexural and direct tensile strength of the concrete. The

experimental studies were carried out on C25 concrete. Cold joint was formed at the angles of 45 and 90 degrees in the concrete samples, which were produced in the shape of a 100\*200mm cylinder and a 100\*100\*500 mm prism. Test samples were prepared first by pouring the half of the concrete samples and forming the cold joint after waiting 2,3,4 and 6 hours, and then by pouring the remaining half of the concrete. Direct tensile and flexural strength tests were conducted on these samples. The results showed that during the formation of cold joint, a longer period of time led to a decrease on the direct tensile and flexural strength of the concrete. This decrease was more evident on the concrete samples poured after 6 hours.

The spread of chloride and its effect on concrete was investigated by Yoo and Kwon (2016). The researchers studied the different loading conditions. Concrete containing GGBFS (ground granular blast furnace slag) in addition to the role of the cold joint in the spread of chloride. The results showed a 30% decrease in the chloride diffusion coefficient from the loading level and an increase in the compressive condition, and with a loading height of 60% or more, the diffusion coefficient reached 1.34 -1.78 times for normal concrete and 2.32-2.52 times for GGBFS concrete. The diffusion coefficient of chloride increases with the square shape of normal concrete, but the linear incremental shape of concrete containing cold joint is evaluated regardless of the type of bonding material. The results showed an increase linearly to 60% of the loading level. And concrete with cold joint increases to 1.37 times for OPC and 1.8 for GGBFS only 48% level ( $15.6 * 10^{-12}m^2/s$ ) of ordinary concrete with cold joint ( $32.4 * 10^{-12}m^2/s$ ).

Wałach (2016) examined the effect of cold joint on beams to the usability limit of beam. Within the scope, the cold joint formed between concretes poured with 7 days intervals. Beams were created in position-angle combinations and 6mm displacement was applied. Four-point bending test was applied. As a result of the study, the cold joint surface should be positioned, cleaned and roughened and by this application the mechanical properties may directly be affected. When the data compared to the control beam, it was found that 45° cold joint angle gives the best results but does not differ significantly from other samples when cold joint formation is in the region where the stress is lowest.

In the study of multi-stage on-site casting simulations with the existence of the cold joint and the absence of the cold joint, Roy and Laskar (2017) took four sets of exterior –beam –column subassemblies under cyclic loading. The bending strength of samples varied 1.2, 1.4, 1.7 and 2.0 MPa. Reduced energy dissipation of cold joint samples was obtained as 24-49% as compared to control samples. Also, a decrease of 22-36% was observed for cold joint samples in their ductility. It was also found that the reduction in the maximum loads of the beam samples with the presence of the cold joint is not significant compared to the control samples.

The cold joint has a great effect on the resistance properties in concrete, and the time has an effect on the cold joint, as Yang et. al. (2018). studied the spread of chloride in the concrete, taking into account the time factor and the cold joint under different loading conditions. The concrete samples contained 0.6 water from weight of bond material and 40% of GGBFS (ground granular blast furnace slag) was replaced. After one year the chloride diffusion coefficients were measured in the treated concrete. The results showed the diffusion coefficients a close similarity between cured concrete for 1 year and curing. Ordinary concrete in the pressure zone, the diffusion coefficient changes slightly to the 30% load level due to pore connectivity decreases but its speed increases to 60%. Loading level causing micro cracks to spread. The effect of the cold joint on chloride diffusion in normal concrete is 99.2% (60% of the tensile load), 81.0% (60% of compressive loading), however they decrease to 80.2% (60% of tensile) and 71.0 (60% of compressive loading). It can be concluded that GGBFS can be used effectively in the case of a cold joint under a large load and in various conditions

Unlu (2018) was studied the effect of cold joint on pressure and flexural strength of the concrete experimentally. The experimental studies were carried out on concrete samples of class C25 produced according to TS EN 206-1 standard. 150\*300 mm cylinders, 150\*150\*150 cubes and 100\*100\*500 mm prism in the form of concrete samples prepared with cold joint having semi-full, 45° and 90° angle. Half of the specimen were poured after 24 hours to form cold joint. He found that the cold joint formed at 45° angle in bending strength tests gave higher strength values compared to cold joints formed at 90° angle.

Roxas and Lejano (2018) investigates the effect of the cold joint on concrete mixed and treated with sea water in addition to the replacement of 30% of Portland

cement with fly ash and its effect on corrosion. The following water/cement ratios (0.30, 0.35, 0.40, 0.45, 0.55 and 0.60) were used. The rectangular prism samples were prepared to study the size of corrosion that the reinforcement is exposed to. It showed a higher rate of erosion with an increase in water content. The corrosion rate was higher in samples mixed with sea water compared to fresh water. The ratio of 0.3 to water content was the least corrosive. With regard to fly ash, the corrosion rate was found to decrease with an increase in the percentage of fly ash. As the permeability of concrete decreases with the addition of fly ash, it makes more resistant to the aggressive environment. The cold joints were also affected very clearly by external factors so that weak places can be easily penetrated.

The formation of the cold joint is greatly affected by the increase in temperature due to the increase in evaporation and the speed of the cement reaction. Research topic consisted of ambient temperature and its effect on cold joint formation in relation to penetration resistance. By determining the flexural strength of concrete beams, the formation of the cold joint is evaluated. At temperatures of 25° and 45° fresh concrete is tested. The experimental results showed that the delay in pouring two consecutive layers is less than the initial setting time of concrete according to ASTM C403 (i.e. 3.5 Newton/mm penetration strength) which causes the formation of the cold joint. It has been found that when the penetration strength is greater than 0.5 N/mm, then a cold joint is forming. This penetration strength is different in ambient temperature (Illangakoon et. al., 2019).

Turan (2019) studied the mechanical characteristics and fracture behavior of cold-jointed concrete under bending with Acoustic Emission (AE), which is a developed nondestructive testing method was aimed. For this purpose, specimens with various joint angles, rehabilitation methods and strength parameters were produced in the laboratory. Beam specimens were tested under four-point bending. She found that load bearing capacity compared to monolithically poured control sample at 90°, 45°, and 0° angles decreased by 40%, 3% and 27 % respectively. The strength for C30-C50 is the same in 90° angle cold joint as compared to the control element result.

Olmez (2019) studied the effect of concrete casting duration and joint geometry on the formation of cold joint. In order to investigate the cold joint phenomenon, specimens such as 100\*100\*500 mm beam, 350\*250\*70mm prism, 100\*200mm

cylinder, and 150\*150\*150 mm cube were casted. Concrete casting has been performed for 8 different time period [- 30, 0, +30, +60, +120, +240, +480, +1140 minutes based on the settlement time] in the C25/C30 strength class in order to allow the cold joint in a controlled manner. In addition, 100\*100\*500 mm beam specimens were produced using seven different concrete connection surfaces (natural, stepped, 30°, 45°, 60°, 90°) to investigate the effect of the concrete connection geometry in term of cold joint. He found delay during casting of concrete, in order to prevent cold joint formation, the second layer must be cast at least 2 hours from the end of the set period, and the first casting surface must be leveled at a 30° angle for better adherence.



### **3. MATERIALS AND METHOD**

This chapter introduces information about experimental methods in producing concrete samples that contain a cold joint with a different angle and a different concrete resistance, along with a description of the main materials used and the engineering tests approved in the Turkish code.

#### **3.1. Materials**

Materials consist of cement, aggregate and water were use in experiments of study without any addition.

##### **3.1.1. Cement**

In this study the cement (32.5 R), produced in Van cement factory was used. This type of cement is produced by grinding pozzolan, which has cement properties of (55% maximum) with Portland clinker with the addition of a percentage of gypsum as an inhibitor. Cement gives late strength when compared to CEMI and CEMII cement. To ensure the safety of the test results, cement was brought in shortly before work and stored in a dry place, away from moisture. Cement properties were in the range given in the specifications according TS EN 197-1:2012 CEM IV/B (P) 32.5R (CSI, 2012). Cement properties are shown in the (Table 3.1) from (Aşkale Çimento).

##### **3.1.2. Aggregate**

Aggregates are inactive and low-cost materials distributed throughout the cement paste, where large quantities of concrete are produced. The volume of aggregate makes up about three quarters of the total volume of concrete. It gives strength to concrete, reduces shrinkage, and makes it more durable. Coarse and fine aggregates used in experiments from Van city. It was obtained from the quarry. Maximum aggregate diameter used was 22.4 mm according TS 706 EN 12620 +A1 in concrete design. In

the production of test samples, the moisture content of the aggregates was checked and used in a short time, and attention was paid not to affect the test results from the aggregate water content (Turkish Standards Institute, 2009).

Table 3.1. Physical, Chemical and Mechanical Properties of Cement Used

Chemical analysis	CEM IV B(P) 32.5 R	Physical Properties	CEM IV B(P) 32.5 R
AL <sub>2</sub> O <sub>3</sub> (%)	6.63	SPECIFIC GRAVITY(g/cm <sup>3</sup> )	2.94
Fe <sub>2</sub> O <sub>3</sub> (%)	3.26	Specific Surface(cm <sup>2</sup> /g)	4339
CaO (%)	50.79	Initial setting	205
MgO (%)	2.53	Final setting	255
SO <sub>3</sub> (%)	2.83	specific gravity(g/cm <sup>3</sup> )	2.94
Na <sub>2</sub> O (%)	0.48	Mechanical properties	
K <sub>2</sub> O (%)	1.39	Compressive Strength (MPa)	
Cl (%)	0.0142	2(day)	24.6
SiO <sub>2</sub> (%)	25.59	7(day)	38
Loss on ignitions	4.37	28(day)	46.2

The size of the aggregate grains is very important in terms of workability, as it affects the water-cement ratio, the bleeding process, isolation and finishing This is an important element in the properties of fresh concrete, which subsequently affects the properties of hardened concrete. Sieve analysis was carried out in the laboratory of the Faculty of Engineering of Van Yuzuncu Yil University to find out the grain size of the aggregate as shown in the (Figure 3.1).

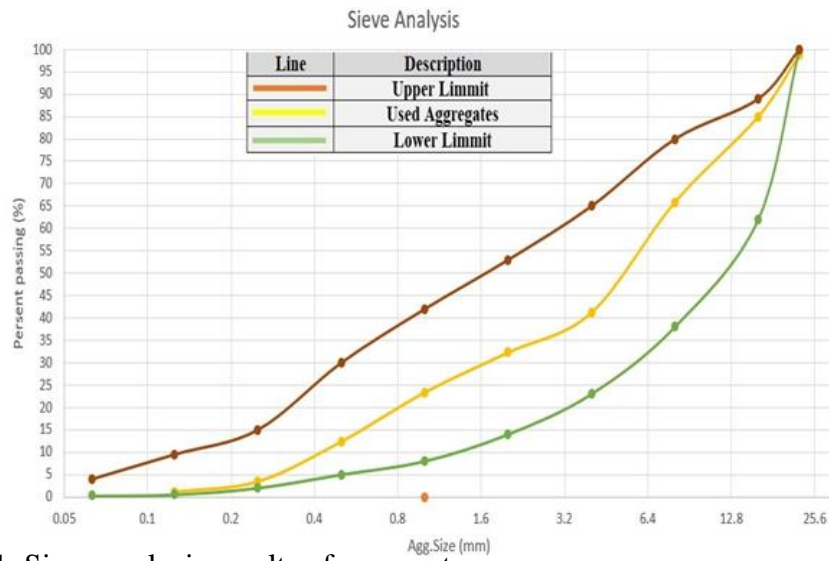


Figure 3.1. Sieve analysis results of aggregates.

### 3.1.3. Water

The water in the mixture was taken from the network in Van city. Fresh water that does not contain any salts or harmful material should be used in preparation of concrete.

## 3.2. Method

In the laboratory of the Faculty of Engineering of Van Yuzuncu Yil University, four concrete mixtures of different resistances were selected. Samples were prepared with different angles to investigate the cold joint effect on compressive and tensile strength of concrete (Figure 3.2). Cylindrical molds were used after curing the samples in a water tank for a week, laboratory tests were carried out for fresh and hard concrete.

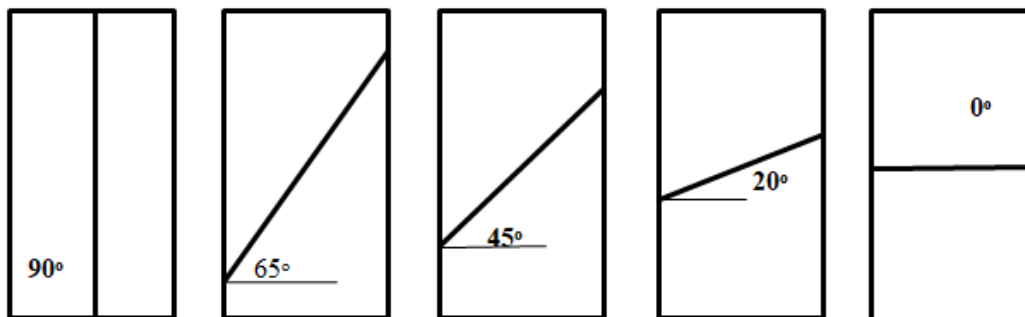


Figure 3.2. Type of cold joint angles.

### 3.2.1. Work plan

Work plan include casting samples of different compressive strength of concrete mixtures (C10, C20, C25, C30 MPa). For each grade of concrete 40 sample are prepared with five angles (0, 20, 45, 65, 90°). For each angle 8 samples were used (Figure 3.3). The total number of samples prepared was 160.

### 3.2.2 Preparation of materials

The materials used in the production of samples were prepared at the laboratory of the Civil Engineering Department of Faculty of Engineering consisting of cement, aggregate and water. (Table 3.2) summarizes the mix ratio of each grade of concrete below.

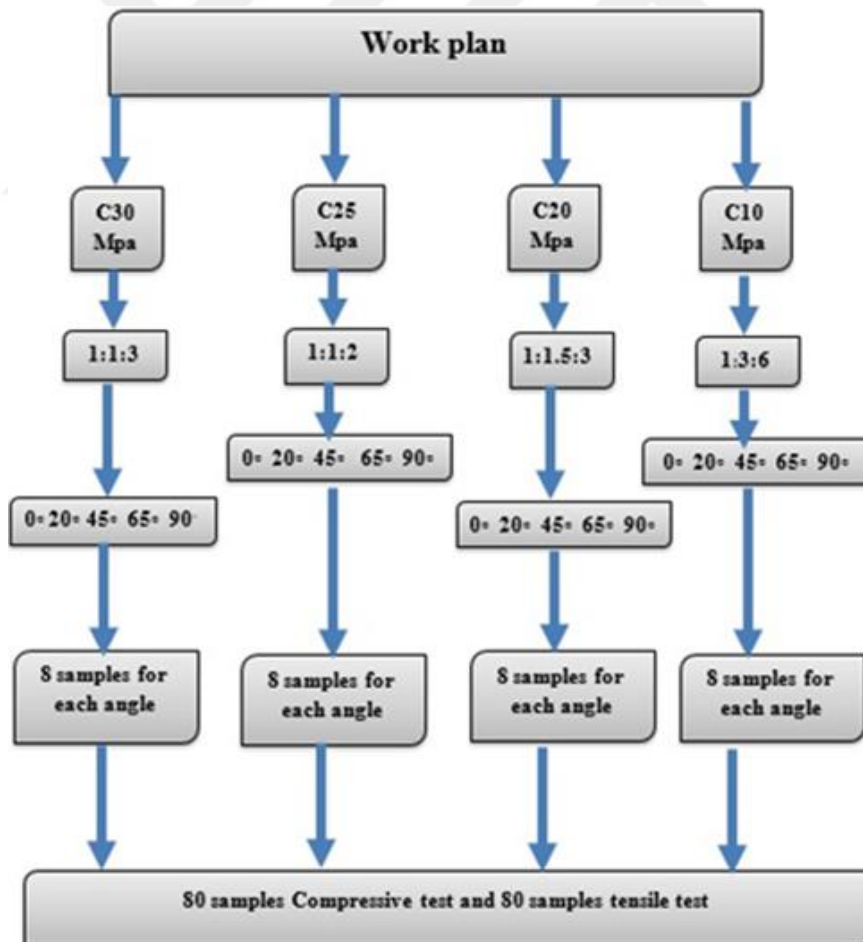


Figure 3.3. Work plan.

Table 3.2. The quantity of ingredient of concrete mixtures

Concrete Grade MPa	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (lt)	W/C
10	226	753	1506	180.8	0.8
20	403	672	1344	221.7	0.55
25	565	565	1130	254.3	0.45
30	452	452	1356	203.4	0.45

### 3.2.3. Tools and devices used in the experiments

- Weighing scales; it is used to determine the proportions of the components of the concrete mixture.
- Laboratory Aggregate Crusher; The aggregate crusher in the Laboratory of Department of Geology was used as shown in (Figure 3.4). The purpose of crushing aggregates is to obtain a 4 mm aggregate and make a correction in the aggregate mixture until the aggregate gradation becomes identical to the specifications as indicated in the results of the sieve analysis.
- Mixer of concrete type (UTC-0752)

The efficient mixing of concrete is essential if quality specimens are to be manufactured. Mixers are designed to mix both wet and dry materials. The mixer bowl can be lifted after the end of mixing in order to empty the mixture easily. The total volume of the bowl is 108 liters, but the optimum volume of the mixer is 56 liters. View of laboratory mixer is given in (Figure 3.5).



Figure 3.4. Aggregate crusher.



Figure 3.5. Laboratory mixer.

- Concrete sample molds (150\*300)mm

The use of cylindrical molds as the stress distribution on the surface is a regular distribution and thus gives a correct picture of the concrete characteristics.

- Sieve analysis

Sieve analysis is used to evaluate how the aggregate grains are distributed through the passage of the aggregate by a series of sieves of different mesh sizes, and then weigh the remaining material from the aggregate on each sieve as part of the whole mass.

- Schematic slump cone apparatus

The slump test is necessary to assess the working of the concrete and determine the amount of water needed for the concrete. Slump test apparatus is a conical metal mold with the height of 30 cm. The bottom of the test apparatus is 20 cm and the upper is 10 cm, and the thickness of the metal should not be less than 1.6 mm.

- Tensile and compressive test apparatus

The aim of using the device is to determine the ability of concrete to bearing deformation under the impact of tensile and compressive stress and study the behavior of cold joints for each samples .

- LVDTs

Compressometers are used to determine the strain and deformation characteristics of concrete specimens. Normal deformation and strain of concrete cylinders is measured by means of compressive tests to assess the modulus of elasticity.

- Curing basin of concrete

Treating samples after casting is very necessary in order to complete the chemical reactions of cement compounds to obtain the required resistance. The treatment is affected by many factors, including the rate of evaporation, where the humidity factor is affected by solar radiation, wind speed, temperature and air humidity. In other words, treatment is done to maintain the temperature and humidity of the concrete to complete the reaction process and develop the resistance over time.

### **3.2.4 Specimen Preparation**

Four mixes were prepared from the normal concrete without any other additives to produce concrete with different strengths which are C10, C20, C25 and C30. Work

was done by changing the proportions of the components through a concrete mixer of the laboratory type with a vertical axis for a period of 4 minutes for the purpose of homogeneity of the concrete mix. The appropriate quantities of coarse and fine aggregates were prepared and the sieve analysis was carried out for the purpose of knowing the granular gradient of the aggregate size and obtaining good workability. Cylinder molds are used with dimensions of 150 \* 300 cm and lubrication was done from the inside. Bases from the wood boards were produced to create inclination which then will enable to have the desired cold joint angle as shown in (Figure 3.6).



Figure 3.6. The inclination of the base under the mold and the molds after finishing casting.

Before that the concrete mixture was poured through two stage to have cold joint. The mold is first filled with three layers, then each level is compacted separately by the tamping rod 25 times so that the number of strikes is distributed regularly on the concrete surface. the operation of pouring half of the molds starts for the purpose of forming a cold joint with a different angle starting from  $0^{\circ}$ ,  $20^{\circ}$ ,  $45^{\circ}$ ,  $65^{\circ}$  and  $90^{\circ}$  as shown in (Figure 3.7).

The molds were left for 24 hours and then the second stage began where the second half of the molds are poured, and the upper level of the mold surface is leveled by a ruler. The image below shows the samples after demolding and cold joint formations clearly shown in (Figure 3.8).



Figure 3.7. The first stage concreting.

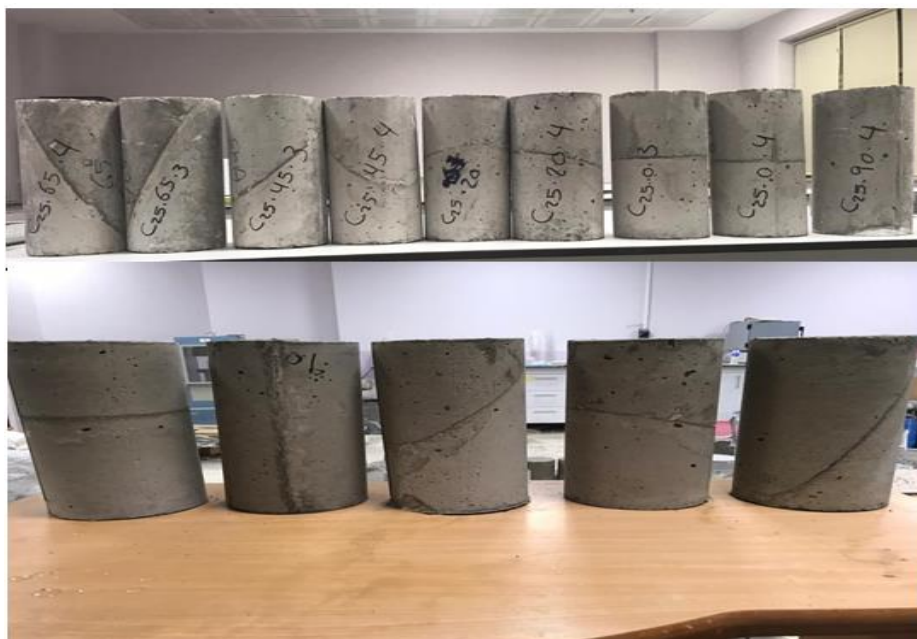


Figure 3.8. The samples show the shape of the cold joints at angle  $0^\circ$ ,  $20^\circ$ ,  $45^\circ$ ,  $65^\circ$ ,  $90^\circ$ .

### 3.2.5 Fresh concrete experiment

The slump test was conducted for the purpose of knowing the workability and determining the consistency of fresh concrete, and checking the amount of water needed to be added to the mix. (Figure 3.9) shows slump test that was done in laboratory. Table 3.3 shows value of slump test results for each grade and the value of slump were equal to 40 to 90 mm and correspond to Class 2 (Table 3.4). The slump test was done according to TS EN 12350-2 - Testing fresh concrete - Part 2.Slump test (Turkish Standards Institute, 2010).

Table 3.3 Slump test value for each grade of concrete

Grade of concrete MPa	Slump test value mm
C10	65
C20	60
C25	40
C30	40



Figure 3.9. The slump test.

Table 3.4. Workability classes and properties (TS EN 12350-2)

TYPE	Slump mm	Use for which concrete is suitable
CLASS1	10 -40	If the amount of water is too low, carefully and strongly placed with vibration, gaps remain in the concrete.
CLASS 2	50 -90	Suitable for vibration compaction, suitable for reinforced concrete structures
CLASS 3	100 -150	It is selected if its reinforcement is too frequent.
CLASS 4	160 -210	The amount of water is too high, it is not suitable for vibration compaction, it is allowed to be used if there is too much reinforcement.

### 3.2.6. Curing of Specimens

After completing the casting process in the laboratory at a temperature of 20 degrees according to the specification TS 1247 'Mixing, placing and concrete curing (Turkish Standards Institute, 1984), the molds are opened 48 hours after casting and then placed in a water pool as given in (Figure 3.10) at a temperature of 22 for a period of one week.



Figure 3.10. Curing basin, the specimens kept 7 days in the tank at temperature 22°.

### 3.2.7 Compressometer

To assess the deformation properties of the concrete cylinders during the compressive test, a compressometer was used as it consisted of two steel rings for attachment to the sample, longitudinal sizing with a spherical volume. Dimensions of the device are 305 \* 152 mm as shown in (Figure 3.11) and is used to determine the modulus of elasticity, the Young's Modulus (and the Poisson's ratio of concrete) in pressure, which conforms to the specifications ASTM C469.



Figure 3.11. Compressometer device.

### 3.2.8. Hardened concrete experiments

#### 3.2.8.1. Compressive strength test of the cylindrical concrete sample

Concrete compressive strength test by 150x300 mm cylinder samples was performed after 28 days from casting the samples according TS EN 12390-3 (Testing hardened Concrete-Part 3) (Turkish Standards Institute, 2010). Four samples for each angle (0, 20, 45, 65 and 90) and same angles for all grades (C10, C20, C25, C30), were prepared. The pressure test was done with testing machine having 2000 KN capacity

with a loading rate of 2kN/sec. Before the tests, surface of the samples was leveled with cement mortar to create a smooth surface according to the specification ASTM C617 / C617M - 15 (Lamond & Pielert, 2006) (Figure 3.12).



Figure 3.12. Caping the lower and upper surfaces of samples.

To know the effect of the cold joint on the compressive resistance and to record the relationship of stress with the strain of each sample, LVDT's, were mounted on the surface of concrete sample to calculate the strain. (Figure 3.13) and (Figure 3.14) show the LVDT's and load-controlled concrete press. Compressive strength of specimens was calculated from Eq 4.1.

$$\sigma_c = P/A \quad (4.1)$$

Where  $P$  = load in kN,  $A$  = Area in  $\text{mm}^2$ ,  $\sigma$  = compressive stress in  $\text{kN}/\text{mm}^2$

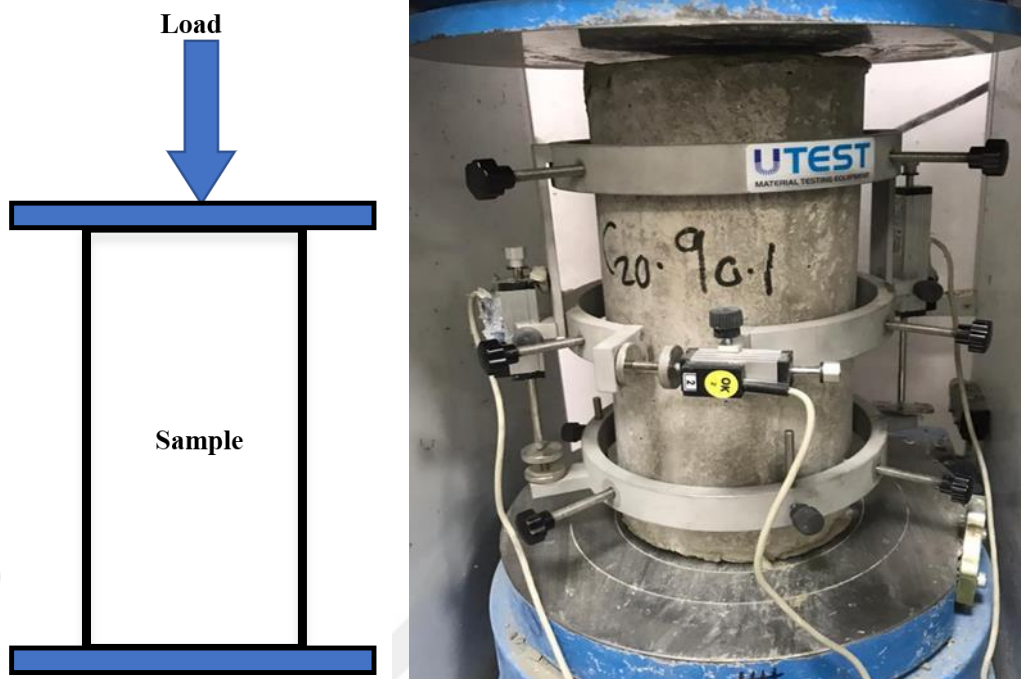


Figure 3.13. A sample with LVDT's ready for compression test a.



Figure 3.14. Load-controlled concrete press.

### 3.2.8.2. Splitting tensile strength of the cylindrical concrete samples

Concrete tensile strength is an important factor and has a great influence on the size of cracks in concrete structures. As concrete is brittle and weak in tension, cracks appear on the concrete body when the tensile stress exceeds the capacity of concrete. It became necessary to know the tensile strength to determine the maximum load at which concrete members would fail.

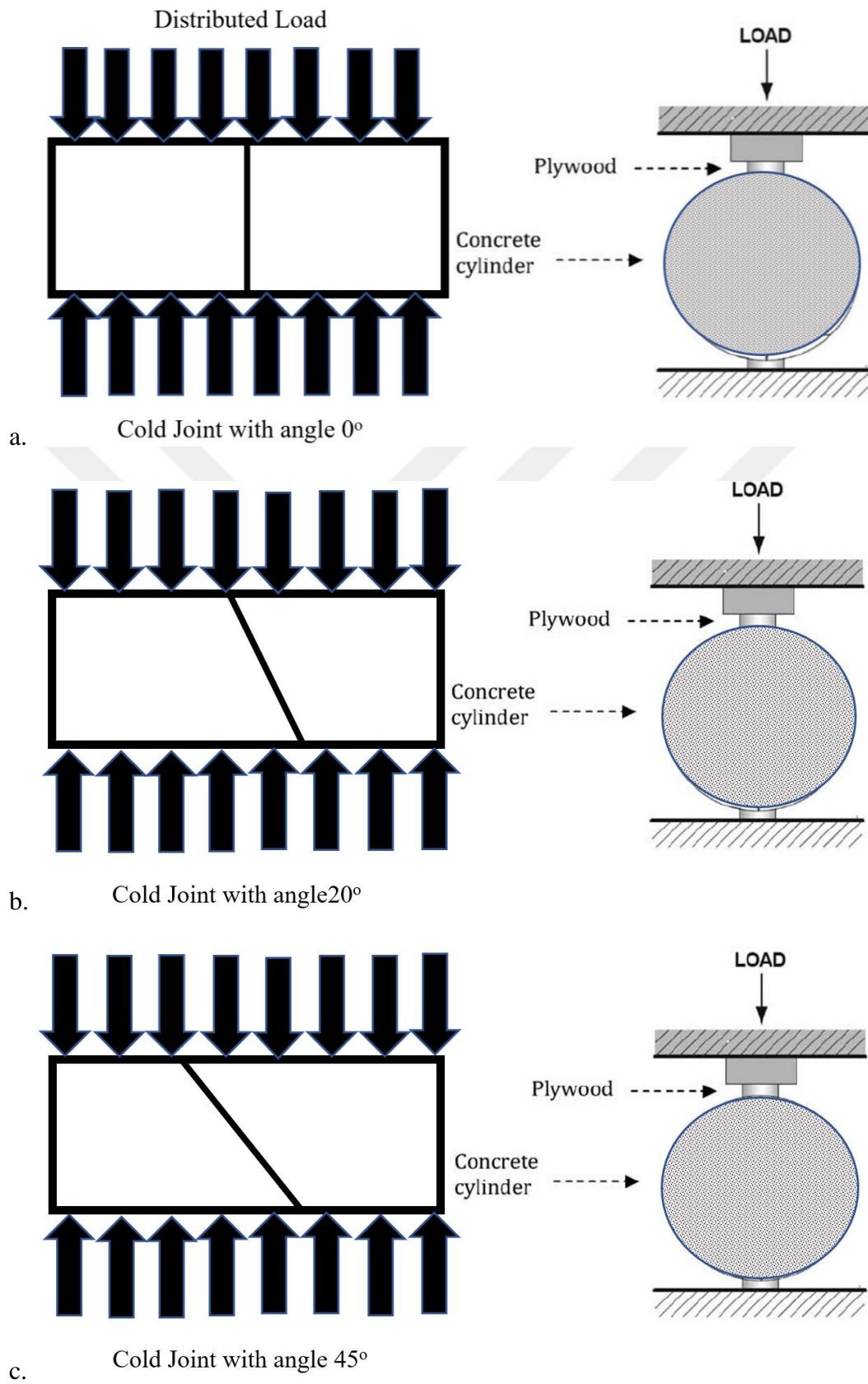
After 28 days from casting according to TS EN 12390-6, (Turkish Standards Institute, 2002) cylinder samples were placed horizontally between the steel heads in concrete press (Figure 3.15, 3.16). The compressive force is applied and uniformly distributed over the length of the specimen, increased till the failure of the specimen. The equation of splitting tensile strength can be calculated as in Eq. 4.2;

$$f_{cts} = \frac{2P}{\pi LD} \quad (4.2)$$

Where  $f_{cts}$  = Splitting tensile strength in MPa, P= max. load in N, D: Sample diameter in mm, L: Sample length in mm.



Figure 3.15. Splitting tensile strength test.



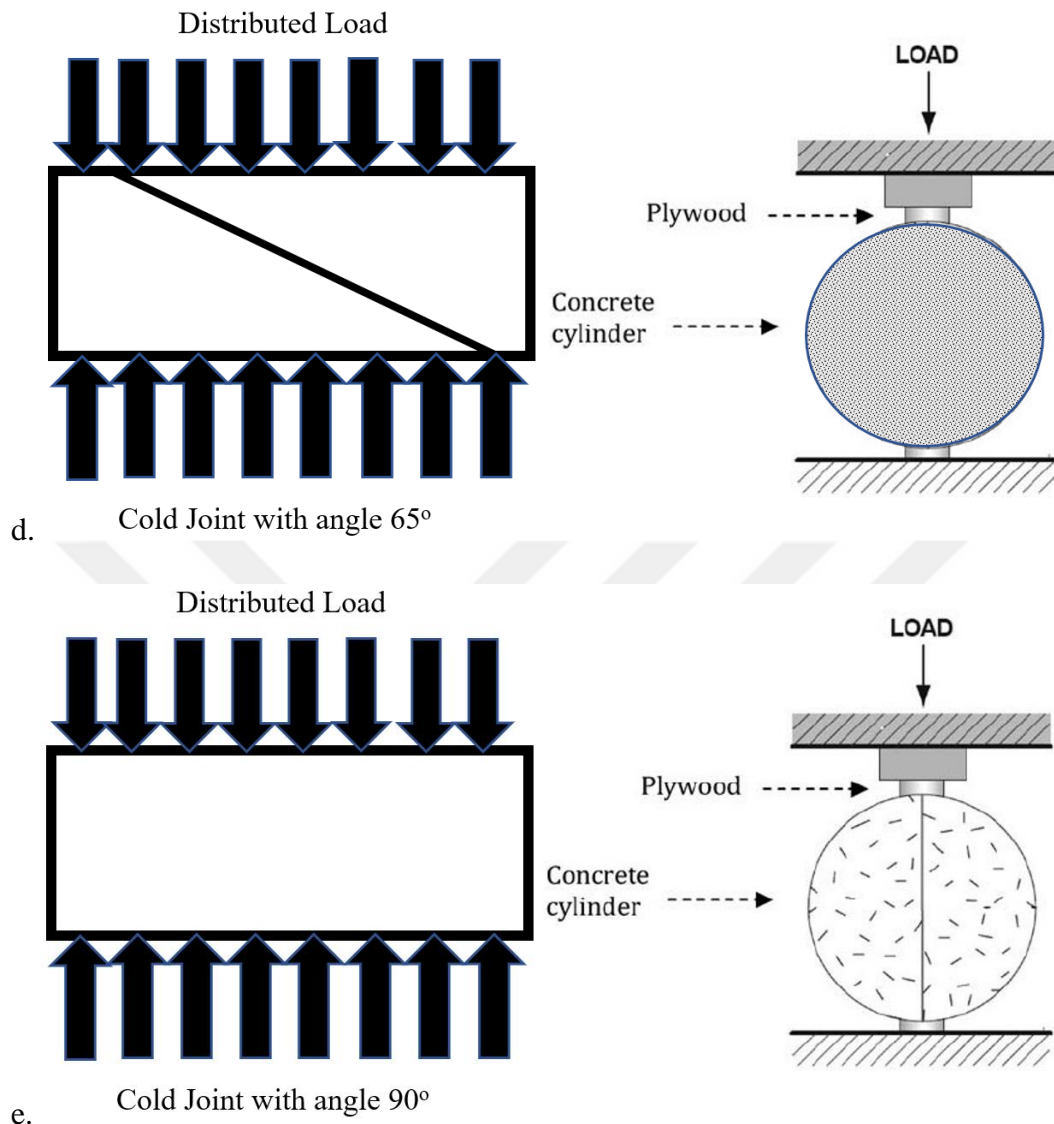


Figure 3.16. Type of loading in splitting tensile test of cold joint with different angle.



## 4. RESULTS AND DISCUSSIONS

### 4.1. Compressive Strength Tests

The compressive strength test of concrete samples was carried out for 80 samples with different strengths of 10, 20, 25 and 30 MPa. For each strength a total of 20 samples were tested. The samples of each strength were poured on five different angles which are 0°, 20°, 45°, 65° and 90°. (Tables 4.1, 4.2, 4.3 and 4.4) show compressive test results for each strength. The table include only 3 samples because the non-standard result was eliminated, the vertical and horizontal displacement measurement was not meaningful therefore they were not presented in this thesis. (Figure 4.1) shows the comparison for all compressive strengths of cold joint angles. In the figure the general trends and equations of the strength in terms of cold joint angle are presented. However, additional tests should be performed in order to increase the confidence level.

Table 4.1. Compressive strength results for 10 MPa concrete samples

Angle	Sample No	Code	Strength (MPa)	Average Strength (MPa)	Standard deviation (MPa)
0	1	C10.0.1	8.29	8.10	0.77
	2	C10.0.2	7.24		
	3	C10.0.4	8.76		
20	1	C10.20.1	8.60	10.11	1.32
	2	C10.20.2	11.05		
	3	C10.20.3	10.68		
45	1	C10.45.2	11.01	10.34	0.79
	2	C10.45.3	9.46		
	3	C10.45.4	10.55		
65	1	C10.65.1	7.31	7.62	0.49
	2	C10.65.2	7.35		
	3	C10.65.3	8.19		
90	1	C10.90.1	7.93	9.58	1.46
	2	C10.90.2	10.18		
	3	C10.90.4	10.68		

Table 4.2. Compressive strength results for 20 MPa concrete samples

Angle	Sample No	Code	Strength (MPa)	Average Strength (MPa)	Standard Deviation (MPa)
0	1	C20.0.1	17.12	19.46	2.03
	2	C20.0.2	20.51		
	3	C20.0.3	20.75		
20	1	C20.20.1	15.31	16.11	1.33
	2	C20.20.2	17.65		
	3	C20.20.3	15.38		
45	1	C20.45.1	17.3	17.58	1.02
	2	C20.45.2	17.44		
	3	C20.45.3	18.02		
65	1	C20.65.1	8.82	10.04	1.00
	2	C20.65.3	10.54		
	3	C20.65.4	10.75		
90	1	C20.90.2	18.47	18.03	0.75
	2	C20.90.3	17.16		
	3	C20.90.4	18.46		

Table 4.3 Compressive strength results for 25 MPa concrete samples

Angle	Sample No	Code	Strength (MPa)	Average Strength (MPa)	Standard Deviation (MPa)
0	1	C25.0.1	20.53	22.00	2.94
	2	C25.0.3	20.08		
	3	C25.0.4	25.39		
20	1	C25.20.1	20.67	19.95	2.61
	2	C25.20.2	22.13		
	3	C25.20.4	17.05		
45	1	C25.45.1	21.37	19.78	1.37
	2	C25.45.2	19.03		
	3	C25.45.4	18.96		
65	1	C25.65.2	12.13	11.65	2.48
	2	C25.65.3	8.96		
	3	C25.65.4	13.87		
90	1	C25.90.2	18.56	20.22	1.64
	2	C25.90.3	20.25		
	3	C25.90.4	21.85		

Table 4.4. Compressive strength results for 30 MPa concrete samples

Angle	Sample No	Code	Strength (MPa)	Average Strength (MPa)	Standard Deviation (MPa)
0	1	C30.0.1	25.74	23.66	2.80
	2	C30.0.2	20.47		
	3	C30.0.4	24.76		
20	1	C30.20.1	21.46	21.87	2.80
	2	C30.20.2	19.93		
	3	C30.20.3	24.22		
45	1	C30.45.1	21.25	22.65	1.30
	2	C30.45.2	22.85		
	3	C30.45.3	23.84		
65	1	C30.65.1	13.81	15.98	1.93
	2	C30.65.2	16.63		
	3	C30.65.3	17.51		
90	1	C30.90.2	25.58	23.40	2.06
	2	C30.90.3	23.14		
	3	C30.90.4	21.47		

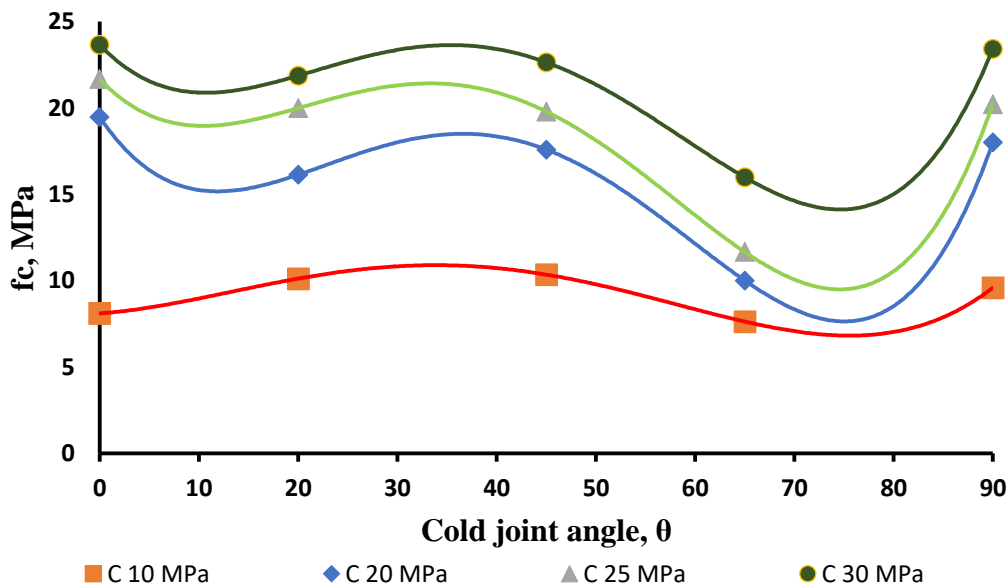


Figure 4.1. Comparison for all compressive strengths of cold joint angles and reference samples.

Standard samples are prepared according to the mix ratio but after the preparation of all samples of cold joint except one sample as given in (Table 4.5). The standard samples were neglected because the casting conditions were different, and thus the results were unacceptable and the compression angle of zero was adopted as control sample.

Table 4.5 Compression test results of the standard samples

Expected Strength (MPa)	Sample No	Code	Strength (MPa)	Average Strength (MPa)
10	1	C10.S.1	10.20	11.72
	2	C10.S.2	12.67	
	3	C10.S.3	12.28	
20	1	C20.S.1	20.35	17.49
	2	C20.S.2	16.08	
	3	C20.S.3	16.04	
25	1	C25.S.1	18.33	19.76
	2	C25.S.2	19.40	
	3	C25.S.3	21.56	
30	2	C30.S.1	25.43	24.74
	2	C30.S.2	26.91	
	3	C30.S.3	21.87	

#### 4.1.1. Effect of the angle zero on compressive strength

Experiments have shown that cylindrical samples with strengths 10, 20, 25, 30 MPa and that have a cold joint with a zero angle as shown in (Figure 4.2) have results close to the standard samples without a cold joint. The reason is that the compressive force is in vertical axis but the cold joint is perpendicular to the loading direction which presses on the upper part of the sample creating greater contact and higher friction. The upper and lower parts were not separated and behaved like a single member. (Table 4.6 and Figure 4.3). In the above table we did not put the value of the standard samples because these are prepared according to the mix ratio but after the preparation of all samples and we found problem in value of control specimen therefore, neglected and comparison 0° angle is taken control specimen.



Figure 4.2. Compression test pictures of 0° cold joints.

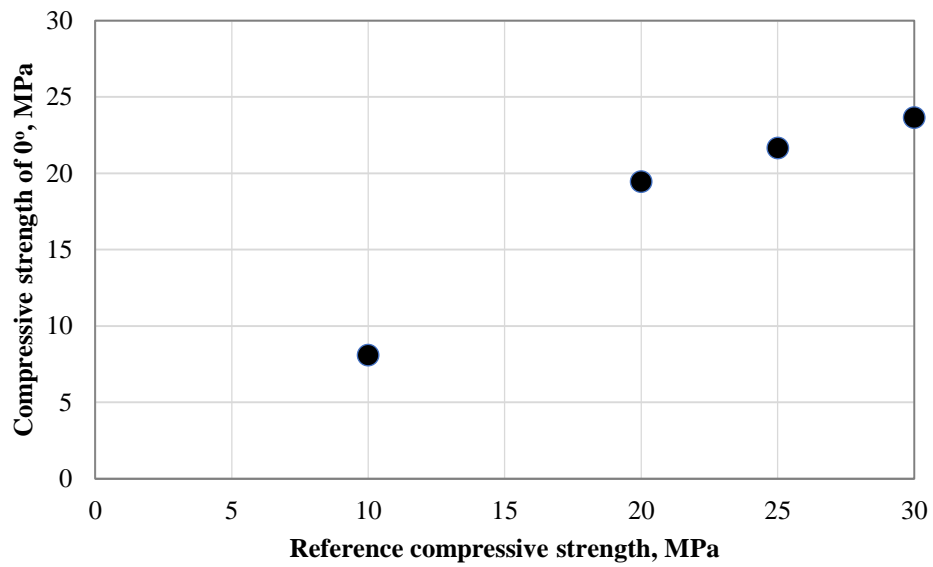


Figure 4.3. Comparison of compressive strengths of 0° angle cold joint and reference samples.

Table 4.6. Compressive strength values of samples for zero angle

Expected Strength (MPa)	Angle	Sample No	Code	Strength (MPa)	Average Strength (MPa)	Standard Deviation (MPa)
10	0	1	C10.0.1	8.29	8.10	0.77
		2	C10.0.2	7.24		
		3	C10.0.4	8.76		
20	0	1	C20.0.1	17.12	19.46	2.03
		2	C20.0.2	20.51		
		3	C20.0.4	20.76		
25	0	1	C25.0.1	20.53	21.67	2.94
		2	C25.0.2	20.08		
		3	C25.0.4	24.39		
30	0	1	C30.0.1	25.74	23.66	2.80
		2	C30.0.3	20.47		
		3	C30.0.4	24.76		

#### 4.1.2. Effect of the angle 90° on compressive strength

As for the angle 90°, its value is close to the zero angle, but it is slightly less than it, so the resistance in this model is also large because the cold joint when its angle is 90° degrees has little effect on the resistance of the model because the cold joint in this case divides the model into two vertical parts as shown in (Figure 4.4) both of which are touching the compressive strength device is equal in one part so that they both fail at the same time. As for the friction force between the two layers of the cold joint, its effect is weak due to the angle shape that is parallel to the compressive strength in the model shown in (Table 4.7) and (Figure 4.5).



Figure 4.4. Compression test pictures of 90° cold joints.

Table 4.7. Compressive strength values of samples for 90° angle

Expected Strength (MPa)	Angle	Sample No	Code	Strength (MPa)	Average Strength (MPa)	Standard Deviation (MPa)
10	90	1	C10.90.1	7.93	9.58	1.46
		2	C10.90.2	10.18		
		3	C10.90.4	10.58		
20	90	1	C20.90.1	18.47	18.03	0.75
		2	C20.90.3	17.16		
		3	C20.90.4	18.46		
25	90	1	C25.90.1	18.56	20.22	1.64
		2	C25.90.3	20.25		
		3	C25.90.4	21.85		
30	90	1	C30.90.1	25.58	23.40	2.06
		2	C30.90.2	23.14		
		3	C30.90.4	21.47		

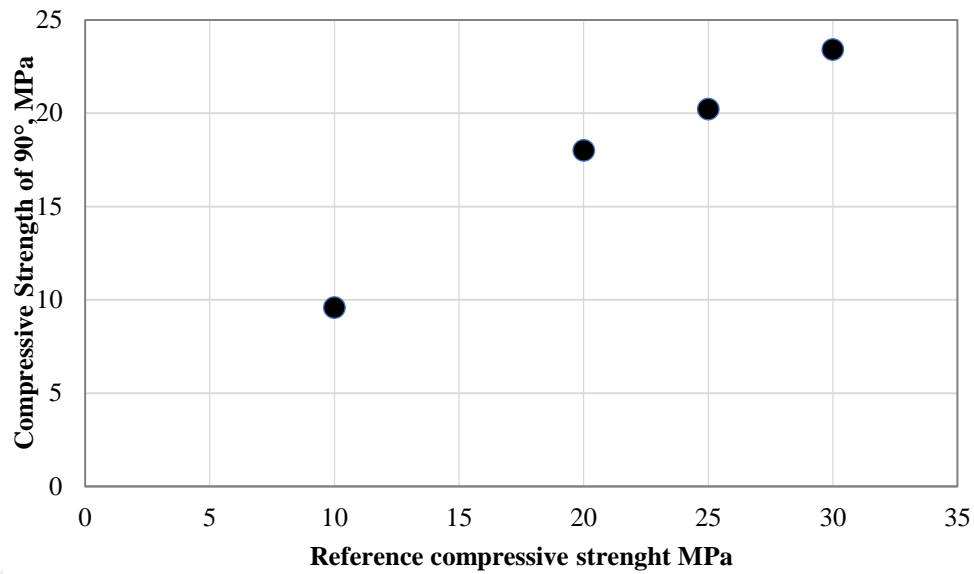


Figure 4.5. Comparison of compressive strengths of 90° angle cold joint and reference samples.

#### 4.1.3. Effect of the angle 65° on compressive strength

The weakest strength of samples was seen when the cold joint angle is 65 degrees (Figure 4.6). The model fails completely overcoming the friction force between the two joint layers where it is very weak due to the slope, so it was found that the compressive strength in (10,20,25,30 MPa) is the lowest among all the specimens. (Table 4.8) and (Figure 4.7).



Figure 4.6. Compression test pictures of 65° cold joints.

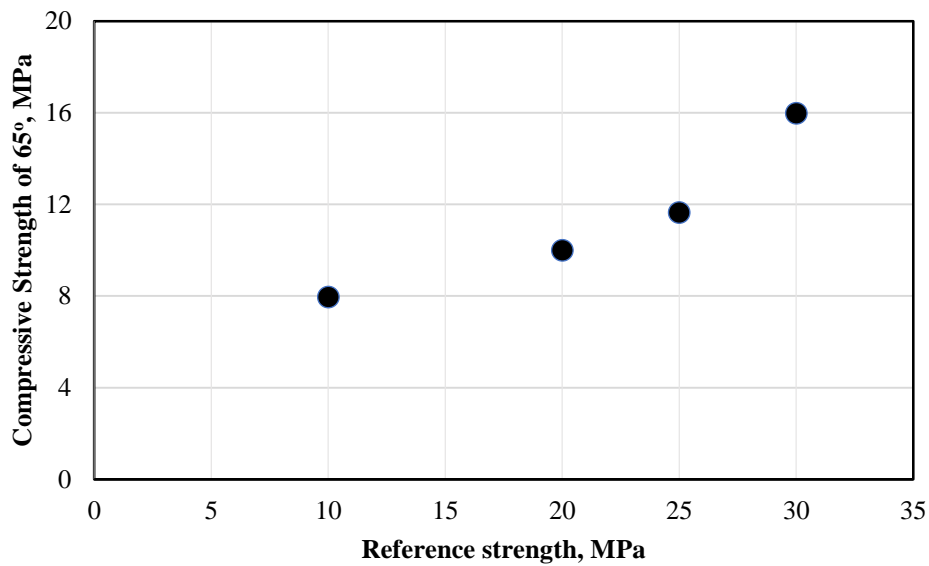


Figure 4.7. Comparison of compressive strengths of 65° angle cold joint and reference samples.

Table 4.8. Compressive strength values of samples for 65° angle

Expected Strength (MPa)	Angle	Sample No	Code	Strength (MPa)	Average Strength (MPa)	Standard Deviation (MPa)
10	65	1	C10.65.1	7.30	7.95	0.49
		2	C10.65.3	7.34		
		3	C10.65.4	8.18		
20	65	1	C20.65.1	8.82	11.14	1.05
		2	C20.65.2	10.53		
		3	C20.65.4	10.75		
25	65	1	C25.65.1	12.13	11.65	2.48
		2	C25.65.2	8.96		
		3	C25.65.4	13.87		
30	65	1	C30.65.1	13.81	15.98	1.93
		2	C30.65.3	16.63		
		3	C30.65.4	17.51		

#### 4.1.4. Effect of the angle 20° and 45° on compressive strength

As for the angle 45 and angle 20 as in (Figure 4.8 ,4.10) with the change of strength, it is noticed that the compressive strength increases with increasing strength, and there is no effect of the angle (Table 4.9-4.10) and (Figure 4.9 ,4.11).



Figure (4.8) Compression test pictures of 20° cold joints.

Table (4.9) Compressive strength values of samples for 20° angle

Expected Strength (MPa)	Angle	Sample No	Code	Strength (MPa)	Average Strength (MPa)	Standard Deviation (MPa)
10	20	1	C10.20.1	8.60	10.11	1.32
		2	C10.20.2	11.05		
		3	C10.20.4	10.67		
20	20	1	C20.20.1	15.30	16.11	1.30
		2	C20.20.2	17.65		
		3	C20.20.4	15.38		
25	20	1	C25.20.1	20.66	19.98	2.61
		2	C25.20.2	22.12		
		3	C25.20.4	17.04		
30	20	1	C30.20.1	21.45	21.88	2.80
		2	C30.20.2	19.93		
		3	C30.20.4	24.22		

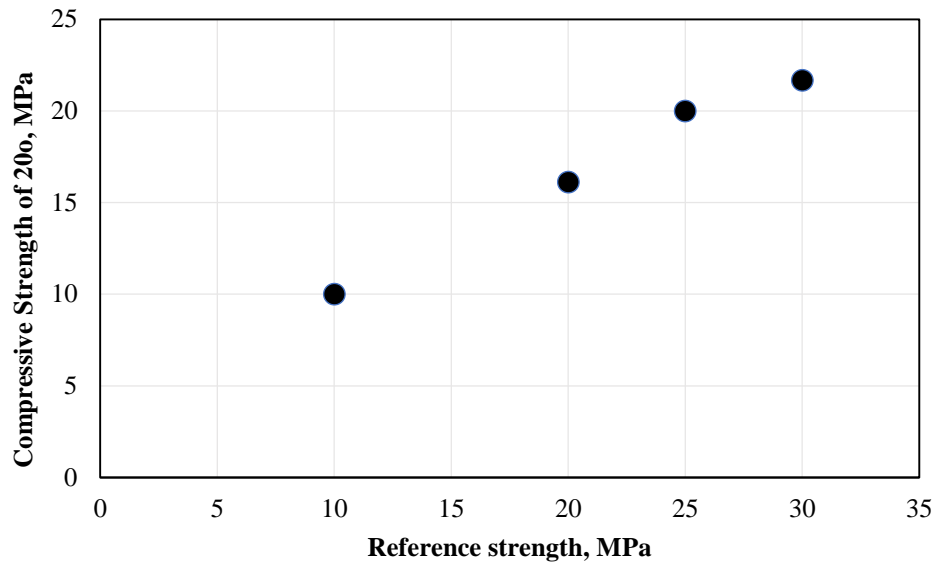


Figure 4.9. Comparison of compressive strengths of 20° angle cold joint and reference samples.



Figure 4.10. Compression test pictures of 45° cold joints.

Table 4.10 Compressive strength values of samples for 45° angle resistance

Expected Strength (MPa)	Angle	Sample No	Code	Strength (MPa)	Average Strength (MPa)	Standard Deviation (MPa)
10	45	1	C10.45.1	11.00	10.33	0.80
		2	C10.45.2	9.45		
		3	C10.45.4	10.54		
20	45	1	C20.45.1	17.3	17.58	1.02
		2	C20.45.2	17.44		
		3	C20.45.4	18.02		
25	45	1	C25.45.1	21.37	19.78	1.37
		2	C25.45.2	19.03		
		3	C25.45.4	18.96		
30	45	1	C30.45.1	21.25	22.63	1.30
		2	C30.45.3	22.84		
		3	C30.45.4	23.84		

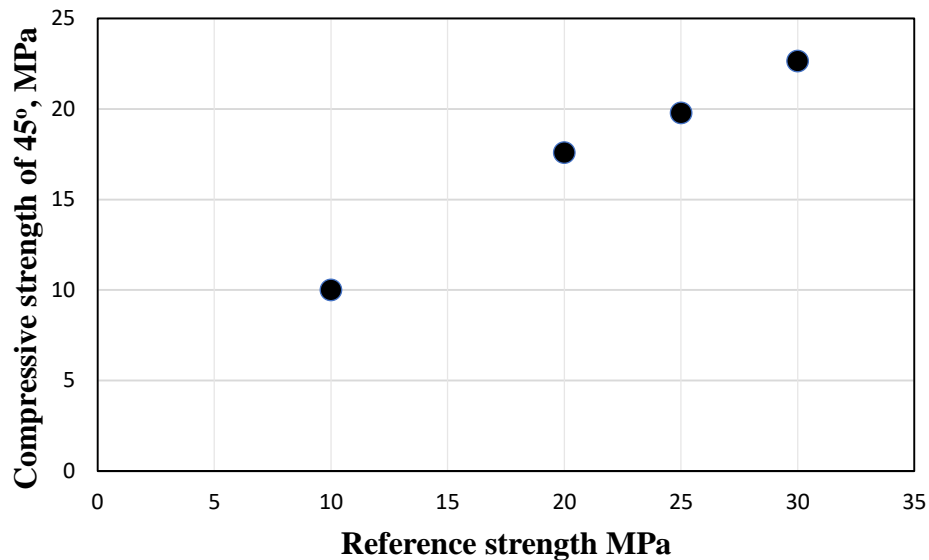


Figure 4.11. Comparison of compressive strengths of 45° angle cold joint and reference samples.

#### 4.1.5. Effect of cold joint angles on compressive strength of 10MPa

As for the results shown by the samples with a resistance of 10 MPa at all angles used in this experiment, they were closer due to the fact that the percentage of cement used was very small, which led to the occurrence of roughness in the surface, especially

in the area of the cold joint, so that the friction force was very high that overpowered the resistance of the samples which led to a failure in the sample without slipping the cold joint as in (Figure 4.12). Therefore, it can be noted that the models were not affected by the cold joint, which led to the approximate of the results as shown in the (Table 4.11)and(Figure 4.13). Samples with a zero-angle joint had less resistance than expected due to failure of the upper part with the lower portion remaining intact without damage.



Figure 4.12. Test pictures of samples for 10 MPa strength with different angles.

Table 4.11. Compressive strength results for concrete samples having 10 MPa strength

Strength MPa	Angle	Sample No	Code	Strength (MPa)	Strength (MPa)	Standard deviation
10	0	1	C10.0.1	8.29	8.10	0.77
		2	C10.0.2	7.24		
		3	C10.0.4	8.76		
10	20	1	C10.20.1	8.60	10.11	1.32
		2	C10.20.2	11.05		
		3	C10.20.3	10.68		
10	45	1	C10.45.2	11.01	10.34	0.79
		2	C10.45.3	9.46		
		3	C10.45.4	10.55		
10	65	1	C10.65.1	7.31	7.59	0.79
		2	C10.65.2	7.35		
		3	C10.65.3	8.19		
10	90	1	C10.90.1	7.93	9.58	0.49
		2	C10.90.2	10.18		
		3	C10.90.4	10.68		

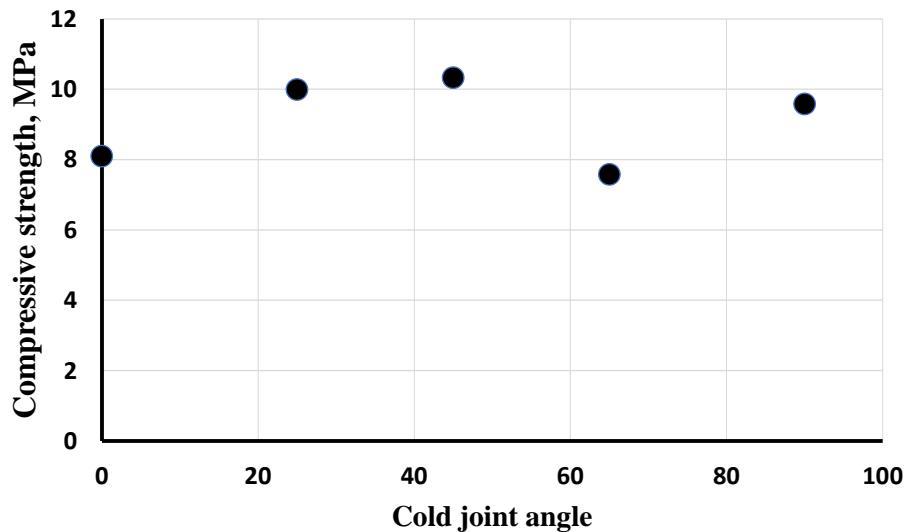


Figure 4.13. Relationship between strength (10) MPa with different cold joint angles.

#### 4.1.6. Effect of cold joint angles on different compressive strengths

Through the experiments, it was found that the best angle for the cold joint, which gave the highest value for compressive strength, is the angle  $0^{\circ}$  degrees, then the angle is  $90^{\circ}$  degrees, and the weakest value for compressive strength is angle  $65^{\circ}$  as shown in (Figure 4.14, 4.15).

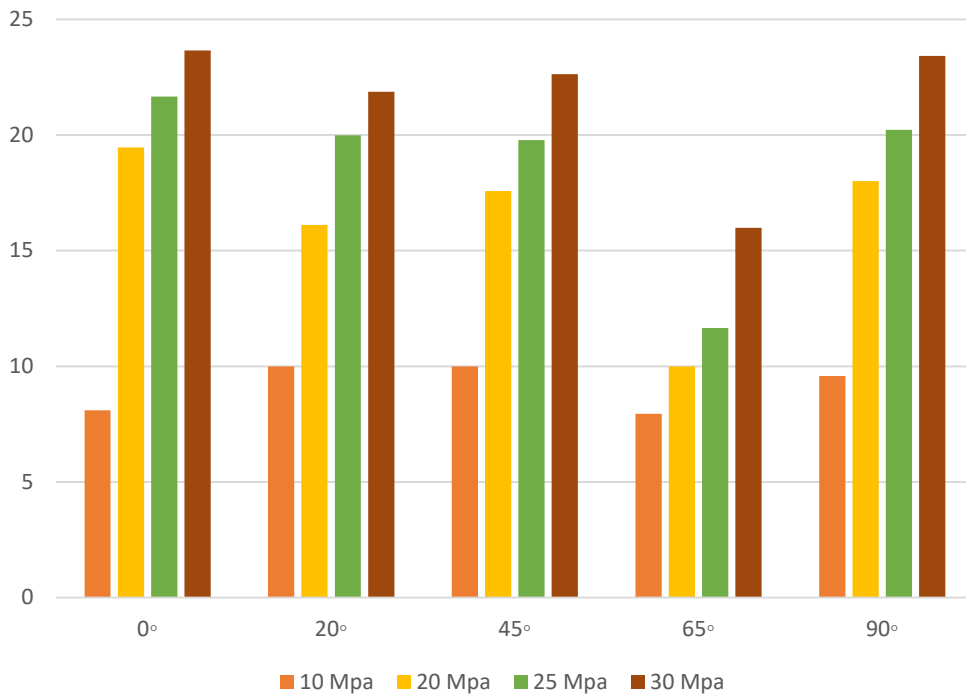


Figure 4.14. Relationships between all strengths with different cold joint angles

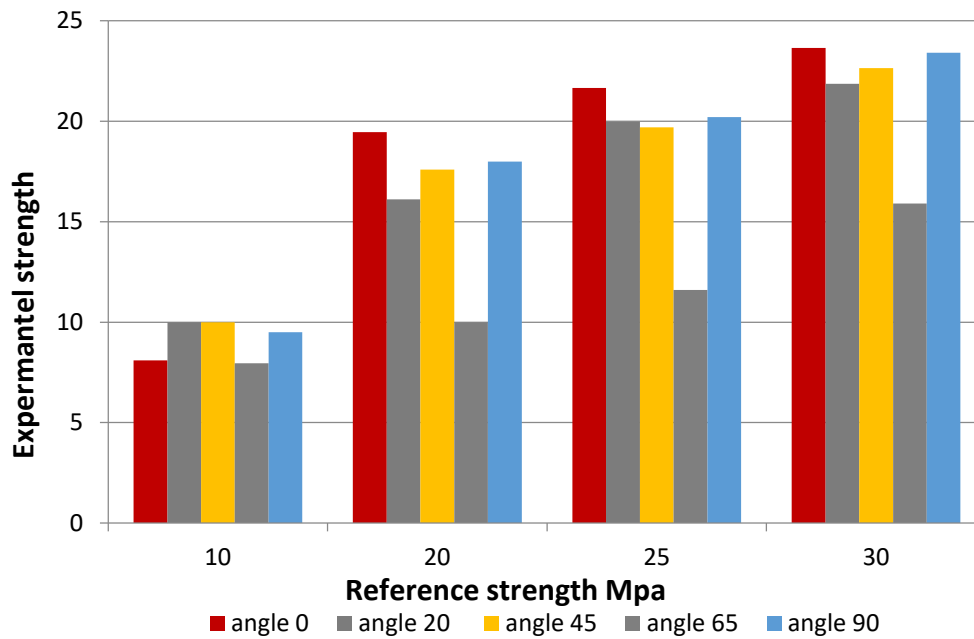


Figure 4.15. Relationships between reference compressive strengths and compressive strengths of cold joint angles.

#### 4.1.7. Comparison with the literature

By comparing the results obtained in the study of cold joints for angles  $0^\circ$ ,  $45^\circ$ ,  $90^\circ$  and different grade of concrete 20, 25, 30 MPa, we find that angle zero gives the highest value and is close to standard samples that do not contain cold joint, followed by angle  $90^\circ$  while angle  $45^\circ$  is the lowest value. This is similar to the results of (Rathi and Kolase 2013) as in (Figure 4.16). The reason for the difference in the curve in this study from previous studies is due to the number of cold joint angles that were used in this study is ( $0^\circ$ ,  $20^\circ$ ,  $45^\circ$ ,  $65^\circ$ ,  $90^\circ$ ). The duration of the formation of the cold joint was 24 hours while the previous study was three angles with the time of forming the cold joint 120 and 180 minutes. In the Rathi and Kolase (2013), the cold joints formed with a time of 120 minutes had less effect on the resistance of concrete and there was a match with the current study in concrete with a degree of 10 MPa, as angle  $45^\circ$  gave a higher resistance than angle  $0^\circ$  and angle  $90^\circ$ . It was explained that the sample with a cold joint fails the upper part of the concrete before the cold joint due to the weakness of concrete and decrease in the amount of cement in the mixture with the increase of the strength of the cohesion in the area of the cold joint due to joint roughness, and the lower part remains intact without any damage.

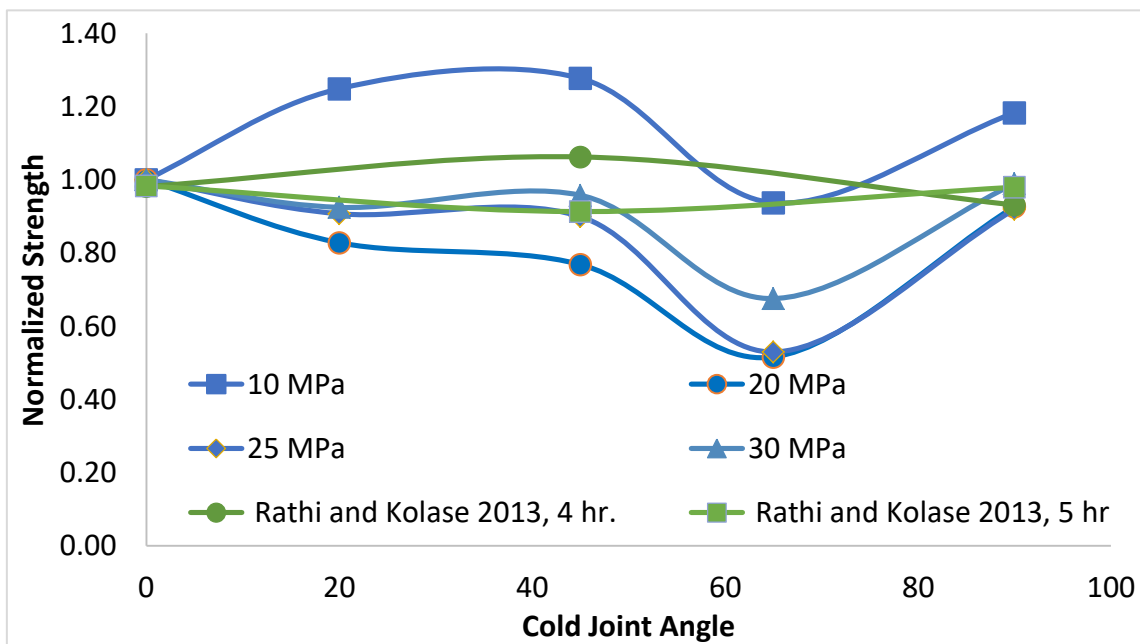


Figure 4.16 Comparisons between the present studies and previous studied (Rathi and Kolase 2013).

The second curve from the previous studies represents the cold joint that was formed after 180 minutes. It was identical to concrete with a resistance of (20, 25 30MPa) as samples with a cold joint at angle of  $90^\circ$ ,  $0^\circ$  gave higher resistance than samples with a cold joint at angle of  $45^\circ$ . We can see a large curvature of the curve in both cases of the present study, and it differs from the previous study. It represents samples that have a cold joint at an angle of  $65^\circ$ , which gave a large decrease in resistance.

Our study correspond with the previous study of the researcher Unlu (2018), where he used concrete of 25 degrees and concrete samples with a cold joint  $0^\circ$ ,  $90^\circ$ ,  $45^\circ$  and the results were close except for the angle 20 and 65 that we carried out and are not found in the previous studies and the samples with a cold joint gave a large decrease in resistance and this can be seen in the decrease of the curve In the (Figure 4.17) below.

The results obtained in the laboratory for samples that contain a cold joint at an angle of  $45^\circ$   $0^\circ$  showed a match with the Kadyrov 2015 study, where samples with a cold joint at an angle of  $0^\circ$  gave similar results to standard samples, while samples with an angle of  $45^\circ$  gave less results, as shown in the (Figure 4.17).

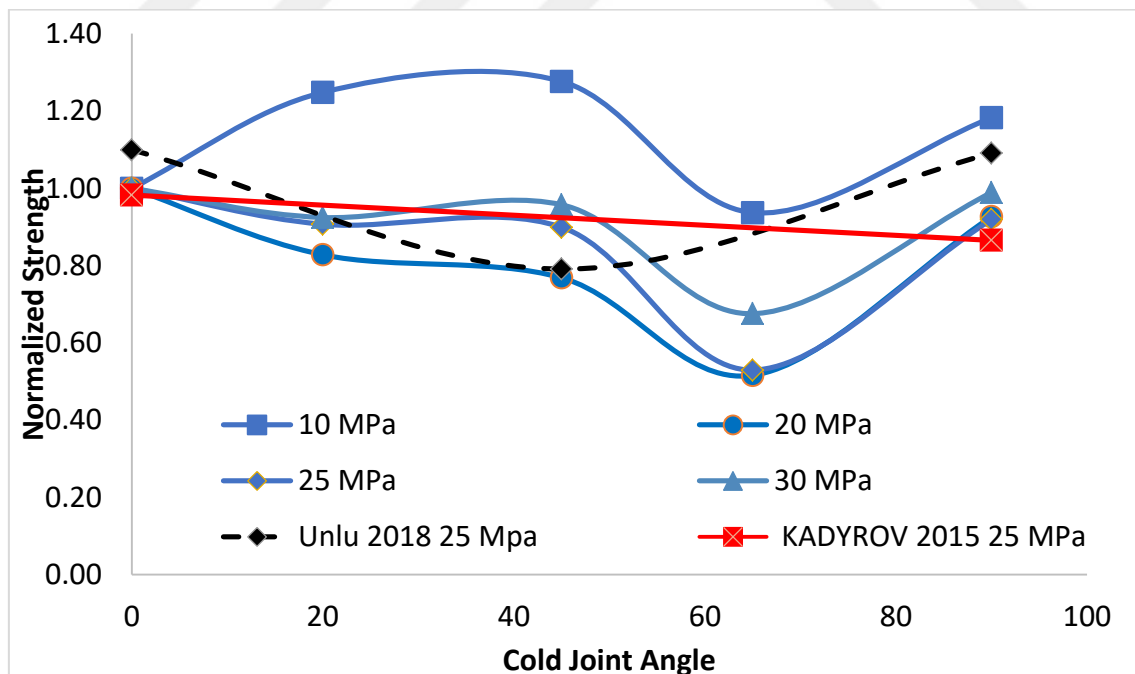


Figure 4.17 Comparisons between the present studies and previous studied (Kadyrov 2015 study and Unlu 2018 study).

## 4.2. Splitting tensile test of concrete

It is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack. Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. Cylinder samples 150\*300 mm with cold joint at 0°, 20°, 45°, 65° and 90° angles the test done after 28 days from casting with Apparatus for Splitting Tensile Test of Concrete, the pictures below show the sample shape after failure and the Tables (4.12, 4.13, 4.14, 4.15) give tensile strengths of each sample in order to study the effect of strength and angle on the tensile strength of concrete.

Table 4.12. Splitting tensile strength for concrete samples with a strength of 10 MPa

Angle	Sample No.	Strength (MPa)	Average Strength (MPa)	Code	Standard Deviation (MPa)
0	1	1.28	1.33	C10.0.1	0.14
	2	1.49		C10.0.2	
	4	1.22		C10.0.4	
20	1	1.52	1.68	C10.20.1	0.22
	3	1.57		C10.20.3	
	4	1.94		C10.20.4	
45	1	1.96	1.84	C10.45.1	0.15
	2	1.67		C10.45.2	
	4	1.89		C10.45.4	
65	2	1.66	1.68	C10.65.1	0.03
	3	1.67		C10.65.3	
	4	1.72		C10.65.4	
90	1	1.26	1.20	C10.90.1	0.32
	2	1.49		C10.90.2	
	4	0.85		C10.90.4	

Table 4.13. Splitting tensile strength for concrete samples with a strength of 20MPa

Angle	Sample No.	Strength (MPa)	Average Strength (MPa)	Code	Standard Deviation (MPa)
0	1	2.42	2.39	C20.0.1	0.15
	2	2.53		C20.0.2	
	3	2.23		C20.0.3	
20	1	2.36	2.54	C20.20.1	0.15
	2	2.59		C20.20.2	
	4	2.66		C20.20.4	
45	2	2.67	2.35	C20.45.1	0.29
	3	2.08		C20.45.3	
	4	2.29		C20.45.4	
65	1	2.42	2.40	C20.65.1	0.16
	2	2.22		C20.65.2	
	3	2.55		C20.65.3	
90	1	1.42	1.49	C20.90.1	0.16
	2	1.67		C20.90.2	
	4	1.37		C20.90.4	

Table 4.14. Splitting tensile strength for concrete samples with a strength of 25 MPa

Angle	Sample No.	Strength (MPa)	Average Strength (MPa)	Code	Standard Deviation (MPa)
0	1	2.14	2.06	C25.0.1	0.15
	2	1.88		C25.0.2	
	3	2.17		C25.0.3	
20	1	1.92	1.99	C25.20.1	0.07
	2	2.07		C25.20.2	
	3	1.97		C25.20.3	
45	1	2.10	2.13	C25.45.1	0.05
	3	2.19		C25.45.3	
	4	2.09		C25.45.4	
65	2	2.37	2.35	C25.65.1	0.05
	3	2.39		C25.65.3	
	4	2.29		C25.65.4	
90	1	1.55	1.62	C25.90.1	0.20
	2	1.85		C25.90.2	
	4	1.45		C25.90.4	

Table 4.15. Splitting tensile strength for concrete samples with a strength of 30 MPa

Angle	Sample No.	Strength (MPa)	Average Strength (MPa)	Code	Standard Deviation (MPa)
0	2	2.92	2.88	C30.0.2	0.08
	3	2.79		C30.0.3	
	4	2.93		C30.0.4	
20	1	2.04	2.14	C30.20.1	0.11
	2	2.04		C30.20.2	
	4	2.25		C30.20.4	
45	1	2.77	2.85	C30.45.1	0.12
	2	2.79		C30.45.2	
	3	2.99		C30.45.3	
65	1	2.40	2.72	C25.65.1	0.28
	2	2.83		C30.65.2	
	4	2.94		C30.65.4	
90	2	1.63	1.76	C30.90.1	0.11
	3	1.83		C30.90.3	
	4	1.83		C30.90.4	

#### 4.2.1. Effect the angle zero on splitting tensile test

The experiment showed that the cylindrical samples with strengths 20, 25, 30 MPa and which have cold joint at zero angle, failed before cold joint failure due to cold joint location relative to tensile force applied to it This is shown in (Figure 4.18) so we find that the tensile strength of the cold angle 0° joint recorded the high value compared to the other used angles.



Figure 4.18. Splitting tensile tests for 20, 25 and 30 MPa with 0° cold joint angle.

#### 4.2.2. Effect the angle $90^\circ$ on splitting tensile test

For the cold joint angle of  $90^\circ$ , 20, 25, 30 MPa strength concretes showed the weakest tensile strength because the angle of the joint is parallel to the failure caused by the tension so that the model is divided into two exactly similar parts through the cold joint due to the increase in the surface area of the joint and this is the main reason why angle  $90^\circ$  is one of the weakest angles of the cold joint. In other words, the cold joint failed before the concrete as shown in the (Figure 4.19).



Figure 4.19. Splitting tensile tests for 20, 25 and 30 MPa with  $90^\circ$  cold joint angle.

#### 4.2.3. Effect the angles ( $20^\circ, 45^\circ, 65^\circ$ ) on splitting tensile test

As for the tensile strength results for cold joint angles ( $65^\circ, 45^\circ, 20^\circ$ ) their results were close due to the location and shape of the cold joint relative to the model and were less or close than angle  $0^\circ$  and greater than angle  $90^\circ$  as shown in (Figure 4.20, 4.21, 4.22).



Figure 4.20. Splitting tensile tests for 20, 25 and 30 MPa with  $20^\circ$  cold joint angle.



Figure 4.21. Splitting tensile tests for 20, 25 and 30 MPa with 45° cold joint angle.



Figure 4.22. Splitting tensile tests for 20, 25 and 30 MPa with 65° cold joint angle.

#### 4.2.4. Effect of cold joint angles on splitting tensile strength of 10 MPa concrete

For concrete samples 10 MPa, the results were almost the same despite the cold joint having angles (20 °, 45 °, 65 °) and the results of samples with the cold joint with an angle of 90° 0° were less, due to the weak resistance of the concrete so that the concrete fails before the cold joint and the direction of the joint with respect to the force exerted on the model as shown in (Figure 4.23).



Figure 4.23. Splitting tensile test pictures of 10 MPa concrete.

#### 4.2.5. Effect of cold joint angles on different tensile strengths

Through laboratory experiments for tensile test, it was found that all samples that have cold joint of angle  $0^\circ$   $20^\circ$   $45^\circ$   $65^\circ$  gave close values except for samples that had a cold joint at an angle of  $90^\circ$  gave a large decrease in resistance (Figure 4.24) shows that.

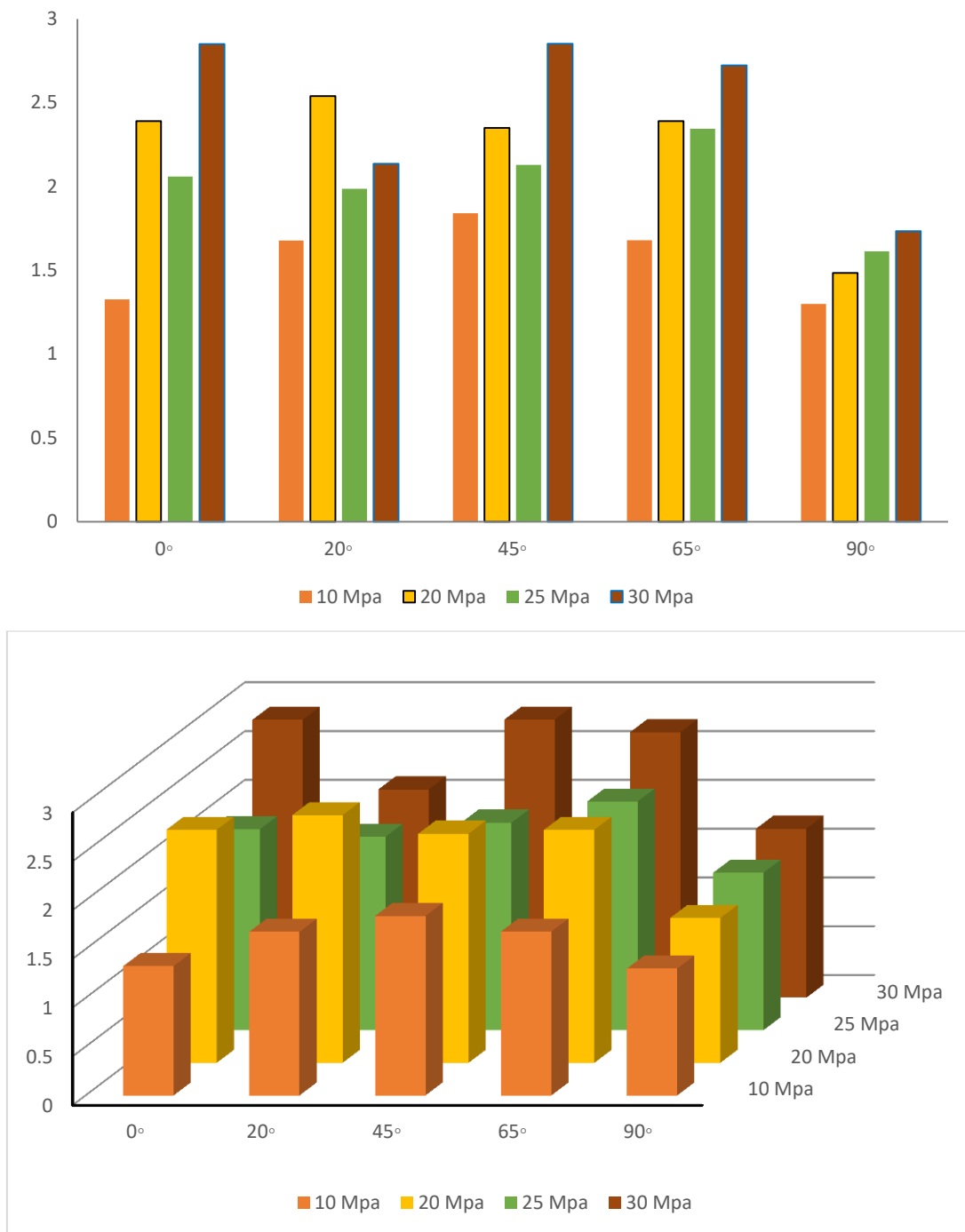


Figure 4.24. Relationships between all strengths with different angles of after splitting tensile test.

## 5. CONCLUSIONS

For compressive test;

- In 10 MPa strength concrete, the cold joint angle had almost no effect due to the weakness in the concrete itself so that the concrete itself failed before the cold joint failed.
- In the strengths of 20, 25 and 30 MPa the angle  $0^\circ$  of the cold joint have results close to standard samples without a cold joint.
- In the strengths of 20, 25 and 30 MPa, the results of the angle  $90^\circ$  of the cold joint are close to the zero angles, but it is slightly less than it. Because the cold joint in this case divides the model into two vertical parts, both of which are touching the compressive strength device is equal in one part so that they both fail at the same time.
- In the strengths of 20, 25 and 30 MPa, for the angle  $45^\circ$  and  $20^\circ$  of the cold joint it is noticed that the compressive strength increases with increasing strength, and there is no effect of the angle. Both the behavior is normal, and the results approximate due to the shape and location of cold joint in the model.
- The weakest strength is found when the cold joint angle is 65 degrees. Since in this angle the cold joint takes up a large part of the model area, the model fails completely overcoming the friction force between the two joint layers where it is very weak due to the angle slope.

For splitting tensile test;

- As for the strength of 10 MPa, the results were almost the same despite the cold joint being at angles ( $0^\circ, 20^\circ, 45^\circ, 65^\circ, 90^\circ$ ) due to the weakness of the resistance so that the concrete fails before the cold joint.
- In the strengths of 20, 25 and 30 MPa and which have a cold joint with a zero angle through tensile test that the concrete failed before the failure of the cold joint due to the location of the cold joint in relation to the tensile force applied to it so as not to be affected by it
- The angle  $90^\circ$  of the cold joint in the strengths of 20, 25, 30 MPa was the weakest tensile force because the joint angle is parallel to the resulting failure resulting in

an increase in the surface area of the joint and this is the main reason why angle 90 is one of the weakest angles of the cold joint.

- The angles 65°,45°,20° of cold joint their results were close due to the location and shape of the cold joint relative to the model and were less than angle 0 and greater than angle 90.



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## GENİŞLETİLMİŞ TÜRKÇE ÖZET (EXTENDED TURKISH SUMMARY)

### SOĞUK DERZİN BETONUN BASINÇ VE ÇEKME DAYANIMINA ETKİSİ

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Kasım 2020, 67 Sayfa

#### 1. ÖZ

Bu çalışma betonlarda soğuk derz probleminin çekme ve basınç dayanımlarına olan etkisi anlamayı amaçlamaktadır. Çalışma kapsamında seri deneyler tasarlanmıştır. Dört farklı beton dayanımı (10, 20, 25, 30 MPa) seçilmiştir. Bu beton dayanımları çok düşük dayanım, 2007 Deprem Yönetmeliği'nde belirtilen minimum dayanım, 2018 Deprem Yönetmeliği'nde belirtilen minimum dayanım ve nispeten yüksek dayanımı temsil etmektedir. Beton dayanımlarına ilave olarak soğuk derz açısı da incelenecek diğer parametredir. Soğuk derz açısının sıfır derece olması durumunda soğuk derz tamamen basınç altında olacağı için control numunesi olarak da değerlendirilebilir. İlave olarak soğuk derzler 20, 45, 65 ve 90 derece olacak şekilde planlanarak açıların çekme ve basınç dayanımına etkisi araştırılmıştır. Deney sonuçlarından 20, 25 ve 30 MPa numunelerde sıfır derecenin soğuk derz olmayan control numuneleri ile benzer dayanımlara sahip olduğu görülmüştür. 90 derece soğuk derz olması durumunda basınç dayanımı sıfır dereceden bir miktar düşük çıkmıştır. 20 ve 45 derece soğuk derz olması durumunda basınç dayanımında bir miktar düşüş görülmüş ise de sonuçların 0 ve 90 derece ile benzerlik gösterdiği gözlenmiştir. Basınç dayanımı noktasında en kötü davranış 65 derece soğuk derz olması durumunda gözlenmiştir. 10 MPa dayanıma sahip numuneler çok düşük dayanıma sahip olduklarından soğuk derz farkı çok hissedilmemiştir. Çekme dayanımı hususunda ise 20, 25 ve 30 MPa'lık numunelerde 0, 20, 45 ve 65 derece soğuk derzin etkisi pek görülmemişken 90 derece soğuk derz olması durumunda en düşük dayanım elde edilmiştir.

**Anahtar Kelimeler:** Soğuk derz, beton derzi, basınç dayanımı, çekme dayanımı.

## 2. GİRİŞ

Bu tez kapsamında farklı soğuk derz düzenlerinde imal edilmiş farklı dayanımlara sahip silindirik betonların basınç ve çekme dayanımlarındaki değişimlerin belirlenmesi amaçlanmıştır. Beton basınç dayanımı 10 MPa (çok düşük dayanımı temsil etmektedir), 20 MPa (2007 Deprem Yönetmeliği'nde belirtilen en düşük dayanımı temsil etmektedir), 25 MPa (2018 Deprem Yönetmeliği'nde belirtilen en düşük dayanımı temsil etmektedir), 30 MPa (nispeten iyi dayanımı temsil etmektedir) seçilmiştir. Bütün beton dayanımlarında 0, 20, 45, 65 ve 90 derecelik soğuk derzler oluşturulmuştur (Şekil 1). Hem basınç hem de çekme testleri için her grupta dörder adet 150 mm çapında 300 mm uzunluğunda standart silindir numuneler üretilmiş ve toplamda 160 numune elde edilmiştir (Şekil 2).



Şekil 1. Soğuk derz açıları.



Şekil 2. Başlık yapılmış silindirik numuneler.

## Basınç Dayanımı Test Sonuçları

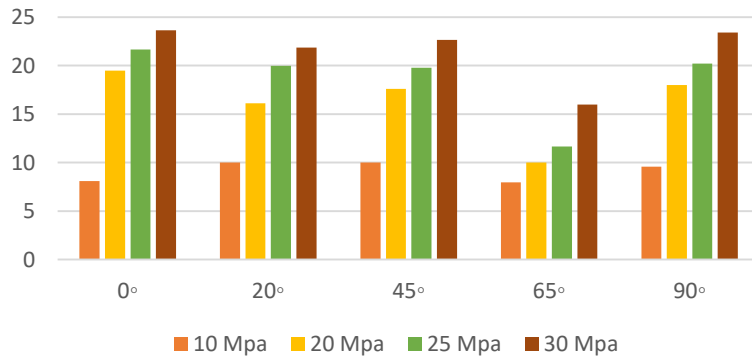
Numuneler beton pres makinesi kullanılarak yük kontrollü bir şekilde basınç altında test edilmiş ve kompresometre ile düşey ve yatay deplasmanlar kaydedilmeye çalışılmıştır (Şekil 3). Basınç dayanımı test sonuçları Tablo 1’de 10, 20, 25 ve 30 MPa için ayrı ayrı verilmiştir. Tablodan görüleceği üzere 65 derecenin haricindeki numunelerde basınç dayanımları birbirine yakın çıkmasına rağmen en düşük dayanımlar soğuk derz açısının 65° olduğu durumda elde edilmiştir (Şekil 4).



Şekil 3. Numunelerin basınç test düzeneği

Tablo 1. Numunelerin basınç dayanım değişimleri

Soğuk Derz Açısı	Ortalama Dayanım (MPa)			
	10 MPa Numune	20 MPa Numune	25 MPa Numune	30 MPa Numune
0	8.10	19.46	21.67	23.66
20	10.11	16.11	19.95	21.87
45	10.34	17.58	19.78	22.65
65	7.62	10.04	11.65	15.98
90	9.58	18.03	20.22	23.4



Şekil 4. Basınç dayanımı test sonuçları

### Yarmada Çekme Test Sonuçları

Silindir yarma yöntemi ile çekme testi yine beton pres makinesinde gerçekleştirilmiştir. Bu testte numneler yatay bir şekilde prese yerleştirilmiş, pres tablası ile temas eden yüzeylere yükü düzgün yayılı uygulamak amacı ile çelik plakalar yerleştirilmiş ve yük kontrollü bir şekilde deney icra edilmiştir (Şekil 5).

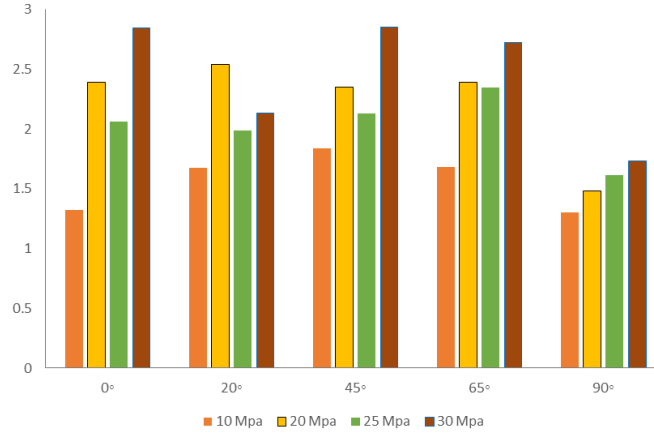


Şekil 4. Silindir yarma düzeneği ile çekme dayanımı testi.

Tablo 2 bütün beton dayanımları için gerçekleştirilen deneylerin ortalama sonuçlarını vermektedir. Test sonuçlarının görüleceği üzere en düşük çekme dayanımı 90 derecelik soğuk derzlerde görülmüştür (Şekil 6) . Bunun sebebi, 90 dereceye sahip soğuk derzin numuneyi ortadan iki eşit parçaya bölmesi ve yarmada çekme deneyinde de çekme gerilmelerinin soğuk derzdeki gibi çatlak oluşturmaya çalışması gösterilebilir.

Table 2. Yarmada çekme deney sonuçları

Soğuk Derz Açısı	Ortalama Dayanım (MPa)			
	10 MPa Numune	20 MPa Numune	25 MPa Numune	30 MPa Numune
0	1.33	2.39	2.06	2.88
20	1.68	2.54	1.99	2.14
45	1.84	2.35	2.13	2.85
65	1.68	2.40	2.35	2.72
90	1.20	1.49	1.62	1.76



Şekil 6. Yarmada çekme deney sonuçları.

## SONUÇLAR

### Basınç testi sonuçları:

- 10 MPa numunelerin dayanımları çok düşük olduğundan soğuk derzin etkisi diğer numunelere nazaran daha az hissedilmiştir..
- 20, 25 ve 30 MPa numunelerde 0° ve 90°'lik soğuk derzlerin kontrol numunelerine yakın dayanımlara ulaştığı gözlenmiştir.
- 20, 25 ve 30 MPa numunelerde 20° ve 45°'lik soğuk derzlerin basınç dayanımlarının kontrol numunelerinin basınç dayanımından çok az farklılık gösterdiği gözlenmiştir
- En düşük basınç dayanımı 65°'lik numunelerde elde edilmiştir. Bunun sebebi, basınç altında numunenin yanal doğrultuda yaptığı genişleme neticesinde oluşan düşey çatlakların yaklaşık 65-90 derece açılara sahip olması ve önceden oluşturulan çatlak düzlemi boyunca numunenin kolay bir şekilde kayması gösterilebilir.

### Yarmada çekme test sonuçları;

- Basınç testinde olduğu gibi yarmada çekme testinde de 10 MPa numunelerin düşük dayanımı sebebi ile soğuk derzin etkisi pek hissedilmemiştir.
- 20, 25 ve 30 MPa numunelerde 0°'lik soğuk derzlerin kontrol numunelerine yakın dayanımlara ulaştığı gözlenmiştir

- 20, 25 ve 30 MPa numunelerde 20°, 45° ve 65°'lik soğuk derzlerin yarmada çekme dayanımlarının kontrol numunelerinin dayanımından çok az farklılık gösterdiği gözlenmiştir
- En düşük yarmada çekme dayanımı 90°'lik numunelerde elde edilmiştir. Bunun sebebi, yarmada çekme deneyinde numunenin ortasından ikiye ayrılacak şekilde çekme kuvvetlerine maruz kalması, 90°'lik soğuk derzin zaten böyle bir çatlak önceden sistemde bulundurması ve numunelerin bu soğuk derz noktasındaki aderansın kaybı ile göçmesi gösterilebilir.



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