MARMARA UNIVERSITY
FACULTY OF ENGINEERING

DESIGNING AND MANUFACTURING OF A CHARPY V-NOTCHING MACHINE

Mithat Gökberk YAVAŞ

Müdek Final Project Commission

The essential features of an acceptable design Project			
		Satisfied	Unsatisfied
1	Mechanical or Thermal Design	✓	
2	Report writing technique	✓	
3	Development of student creativity		✓
4	Use of open-ended problems		✓
5	Formation of design	✓	
6	Problem statement and specification	✓	
7	Synthesis of alternative solutions		✓
8	Feasibility	✓	
9	Detailed system description	✓	
10	Consideration of constraints (e.g. economic, safety, reliability, etc.)	✓	
11	Utilization of engineering and scientific principle	✓	

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Prof. Dr. Bülent Ekici,	
Dr. Öğr. Üyesi Uğur Tümerdem	
Ar. Gör Serkan Öğüt	

GRADUATION PROJECT REPORT

Department of Mechanical Engineering

Supervisor
Prof. Dr. Paşa YAYLA

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Designing and Manufacturing of a Charpy V-Notching Machine

by

Mithat Gökberk YAVAŞ

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Signature of Author(s) .... Mithat Gökberk Yavaş

Department of Mechanical Engineering

Certified By ....**Prof.Dr. Paşa YAYLA**...............

Project Supervisor, Department of Mechanical Engineering

Accepted By...............**Prof.Dr. Bülent EKİCİ**...............

Head of the Department of Mechanical Engineering

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June, 2021 **Mithat Gökberk YAVAŞ**

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ABSTRACT

Designing and Manufacturing of a Charpy V-notching Machine

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Product reliability and durability play a significant role in recent years. Many tests are performed to observe material behavior and to select the right materials in engineering calculations. One of these tests is the impact test and it gives information about the impact toughness of the material. Impact tests are guiding about materials accordingly. The impact test can be done in two different ways, one is the Charpy impact test, and the other is the Izod impact test. In order to perform the Charpy impact test, there must be a notch in the standards determined in the middle of the prepared samples. Although there are three type of notch, V-notch is most commonly used. Charpy V-notching machines allow these notches to be quickly and precisely. In this study, it is aimed to design and manufacture entry-level a motorized notching machine used for plastic specimens that cost less than the notch machines on the market. It was decided to design a motorized rotational Charpy V-notching machine suitable for this purpose and it was manufactured.

ÖZET

Charpy V-çentik Açma Makinesi Tasarımı ve İmalatı

Mithat Gökberk YAVAŞ

Ürün güvenirliliği ve dayanıklılığı son yıllarda önemli bir rol oynamaktadır. Mühendislik alanında, malzeme davranışlarını gözlemlemek ve doğru malzemeleri seçmek için birçok test yapılır. Bu testlerden biri de darbe testidir ve malzemenin darbe tokluğu hakkında bilgi verir. Darbe testleri buna göre malzemeler hakkında yol gösterir. Darbe testi, biri Charpy darbe testi, diğeri ise Izod darbe testi olmak üzere iki farklı şekilde yapılabilir. Charpy darbe testinin yapılabilmesi için hazırlanan numunelerin ortasında belirlenen standartlarda bir çentik olması gerekmektedir. Üç çeşit çentik tipi olmasına rağmen, V-çentik en yaygın olarak kullanılandır. Charpy V-çentik açma makineleri, bu çentiklerin hızlı ve hassas şekilde olmasını sağlar. Bu çalışmada, piyasadaki çentik makinelerinden daha düşük maliyetli, plastik numuneler için kullanılan giriş seviyesi motorlu bir çentik açma makinesi tasarımı ve imalatı amaçlanmıştır. Bu amaca uygun motorlu dönel Charpy çentik açma makinesinin tasarımına karar verildi ve üretildi.

SYMBOLS

$\boldsymbol{a_{cN}}$: Impact toughness

$\boldsymbol{b_n}$: Remaining width of specimen

$\boldsymbol{E_c}$: Corrected energy

ABBREVIATIONS

ASTM **:** American Society for Testing and Materials

CVN **:** Charpy V-notch

ISO **:** International Standard Organization

USE **:** Upper shelf energy

DBTT **:** Ductile-brittle transition temperature

PPRC : Polypropylene random copolymers

HDPE : High density polyethylene

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1. INTRODUCTION

The importance of production has increased in these days. With the developing technology, many different materials have started to be produced and continues. There should be information about the behavior of these materials under different conditions because suitable materials must be used for each product. Therefore, the manufactured product or the material used must be checked in various tests to determine whether it provides the required qualifications. The materials used in many industrial applications are damaged according to the ambient temperature and the applied load. When deciding which material is suitable for the design, it is necessary to know at what temperatures the material is ductile and which temperatures it is brittle and how much energy is absorbed when it is breaking. Some tests are done to reach this information and one of them is the impact test.

Impact tests results give information about the toughness of the material. Toughness refers to the total energy absorbed by the material until it breaks. Toughness values of materials can vary depending on many factors.

The fracture energy value determined by the impact test is not used as a numerical value. It is not using for formulas. It gives information about its ductility and brittleness and makes this value meaningful. The impact test is often used to observe the connection between them and their relationship to the temperature.

Impact tests are performed in two ways. One of them is the Charpy impact test and another one is the Izod impact test. The basic principles of the Charpy and Izod tests are similar. Both are performed to evaluate the ductility properties of the material and determine the material’s ability to absorb energy in sudden impacts. The main difference between them is the dimension of the specimen for the same material and the other one is the position of the specimen. The Charpy specimen is placed horizontally and Izod specimen is placed vertically on the impact test device. In the Charpy impact test both ends of the specimen are fixed, but only the bottom end is fixed for the Izod impact test. Hammer strikes at the middle point of the material but the opposite side of the notch in the Charpy impact test. Hammer strikes the top of the materials on the notch side in the Izod impact test.

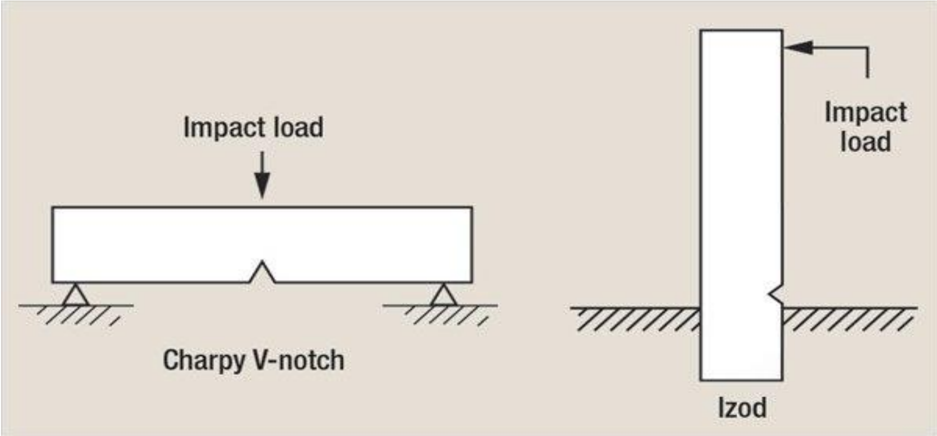

Figure 1. 1. Types of impact test

One of the common features between them is that two of them can be used for metal materials. On the other hand, it is used for plastics.

In order to obtain accurate results from the impact test, the specimen must be prepared in accordance with the specified standards. There are notches in different shapes and depth desired specimen. These are V-notch, U-notch, and keyhole, as shown in Figure 1.2. The notching machine is needed to prepare different kinds of these specimens. High precision notching machines are used to minimize the margin of error in the impact test. The main purpose of this thesis is to design and manufacture Charpy V-notch machine, therefore the Izod impact test and the other shape of notches will not be mentioned.

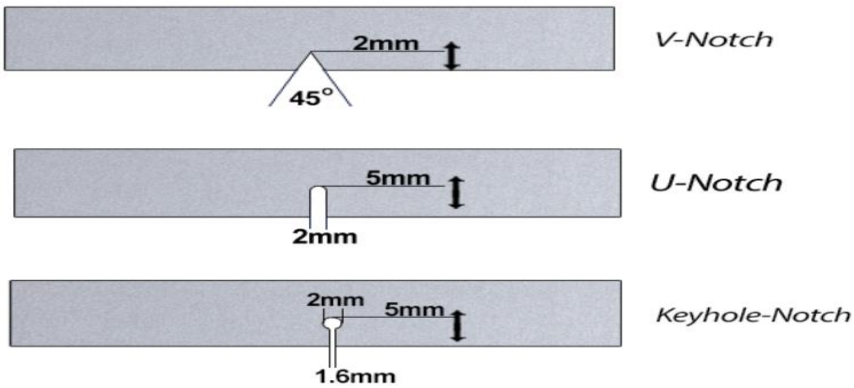

Figure 1. 2 Types of notches

1.1. Charpy Impact Test and Historical Development

The basis of many testing machines that we use today is based on research and discovery in the 1800s. In that era, impact-pendulum test method and associated was developed. Georges Augustin Albert Charpy was one of the members of this association. In 1901, Charpy worked on the results of a test for impact resistance steel with pendulum and Charpy presented a paper to Association and also, in 1905, Charpy had offered a machine design similar to the machines used today, and it accepted the Charpy method [1]. Charpy impact test, which is used today, was formed with later studies and determined standards.

The Charpy impact test is a high strain-rate test that involves striking a standard notched specimen with a controlled weight pendulum. The Charpy impact test is also known as Charpy V-notch test. The Charpy impact test gives the results of the energy absorbed during the breaking of the specimen. In other words, Charpy impact test is performed to reveal the resistance of the materials against breaking according to test standards. Although it is usually used for metals, it can be used in some other materials, such as plastics. Charpy impact test provides important data on whether the material is ductile or brittle. A brittle material will absorb a small amount of energy when impact tested, a ductile material absorbs a large amount of energy.

The Charpy impact test is performed on the pendulum impact machine. Basically, it consists of a pendulum, scale, supports and test piece.

Samples should be prepared according to the standards determined according to the type of material to be tested. For metallic material, according to ASTM E23 standard, CVN specimen is 55 mm long, 10 mm square and has a 2 mm depth notch with a tip radius of 0.25 mm machined on one face. Different notched radius or unnotched specimens can be used in some materials. It can also use for polymers and composites materials. A schematic diagram of the specimen is shown in Figure 1.3.

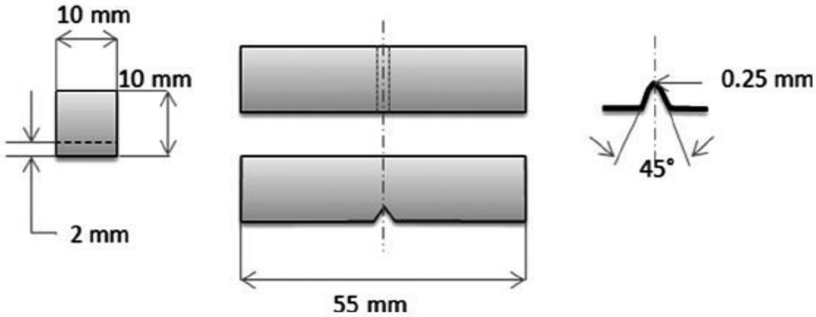

Figure 1. 3 Schematic diagram of specimen according to ASTM E23

This notch, which can be either V-shaped or U-shaped, is placed facing away from the pendulum and helps to concentrate the stress and encourage fracture. The Charpy impact test is most commonly performed ASTM E23, ASTM A370, ISO 148. There also standards for plastics or polymers such as ASTM D6110 and ISO 179-1.

The notch specimen is placed facing away from the pendulum. According to standards, specimens are notched at an angle of 45±1° with a radius of curvature at the apex of 0.25±0.05 mm. Then, a pendulum with a certain weight is released from a certain height. After a pendulum is released from this height, it breaks the sample with potential energy and the specimen absorbs the energy of the pendulum. A pendulum is raised certain height with residual energy. The potential energy difference between these two heights is called breaking energy, also known as notch impact energy. Charpy impact test equipment is shown in Figure 1.4.

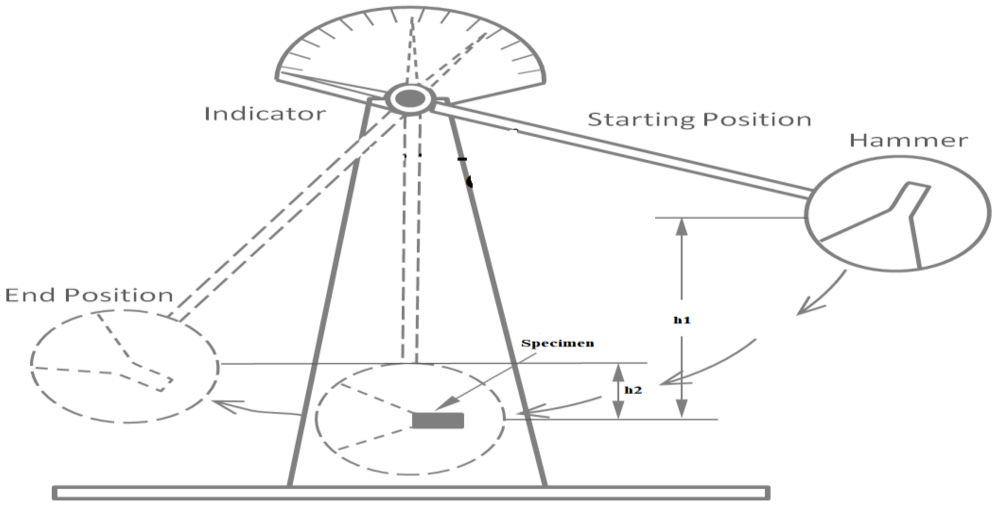

Figure 1. 4 Schematic drawing for Charpy impact apparatus

1.2. Charpy Notching Machine

The conventional manufacturing of specimens for impact tests needs high precision adjusting of the specimen and specimens must be inside the dimensional limits of standards. One of the most critical points of the Charpy impact test is the property of the notch. The notch depth and quality of the specimen are important to the Charpy impact test results. Because these materials must be grouped in order to be compared correctly. In accordance with this purpose, a notching machine is developed to prepare V-notched specimens for impact test to comply with the standards. Since there will be different results on different materials, the standards are also determined according to material type.

The machines used for the preparation of these specimen are called Charpy notching machines. CVN machines are often used in laboratories and testing centers. The basic parts of CVN machine consist of a notch knife, precision measuring instruments for adjusting the depth of the notch and power to cut the material.

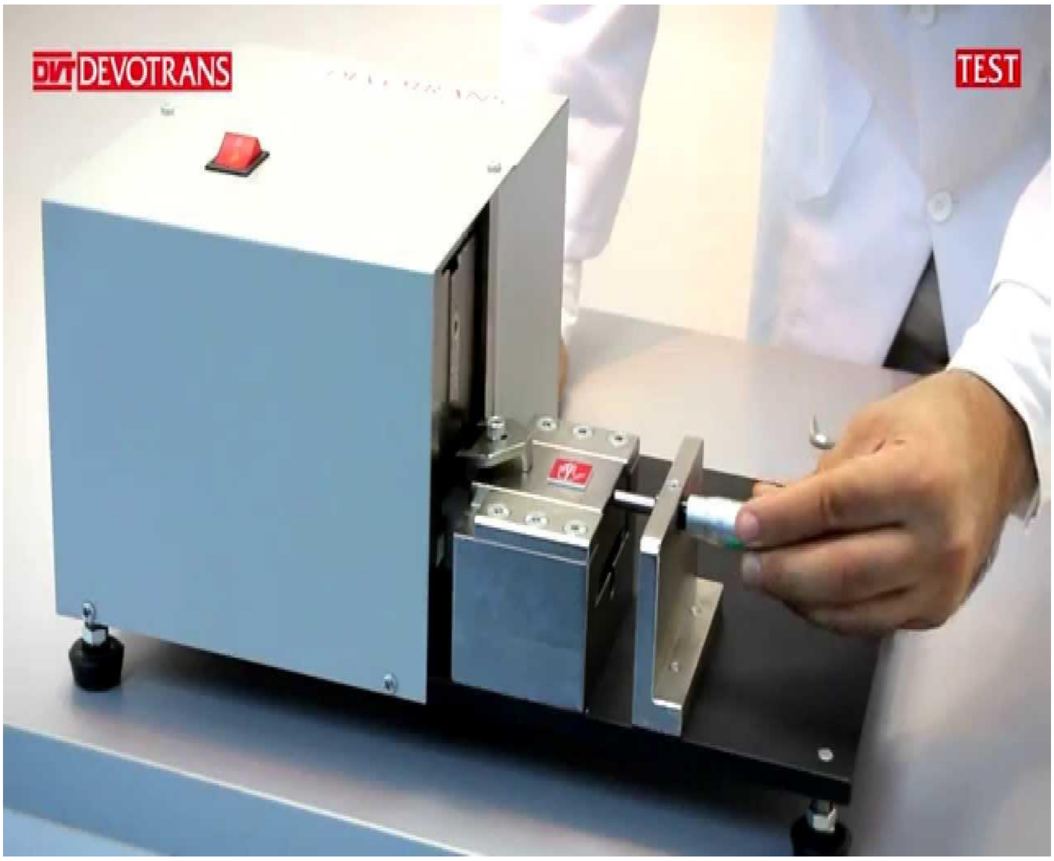

Figure 1. 5 A CVN machine which belongs to Devotrans company.

There are many different notch preparation methods. These preparation methods lead to certain differences in materials such as notch angle, surface conditions. Notches can be prepared using grinding machines and broaching machines. Broaching machines are preferred over grinding machines for metallic materials because broaching machines can give more load for the notching. So, the broaching method is used for metal materials to notch. Notching machines used may vary according to users' requests and standards.

The specimen can be prepared to suit many different materials such as plastics and metals. It is generally the basis ISO 179 for plastics and ASTM E23 for metallic materials. Specimen geometries must be produced in accordance with these standards. The Charpy notching machine can use to prepare the non-metal material specimen, such as plastics, organic glass according to ISO 179 standards. According to ISO 179-2000, the specimen can be 80 mm in length, 10 mm in width and 4 mm in thickness. The width of the specimen is varying between limits. Specimen size can be 55 mm length, 10 mm width and 10 mm thickness according to ASTM E23 for the metallic material. Different radius can be used for the specimen. Notches can be produced in different shapes such as U, V and keyhole.

Specimens are shown in Figure 1.6 and Figure 1.7.

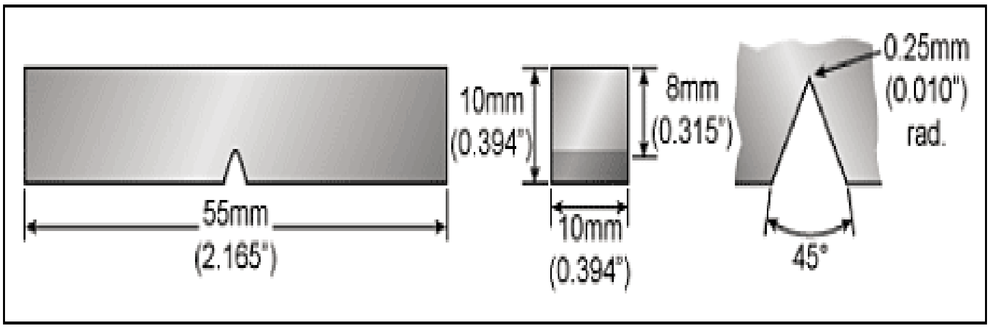

Figure 1. 6 Largest Charpy V-notch specimen according to ASTM E23

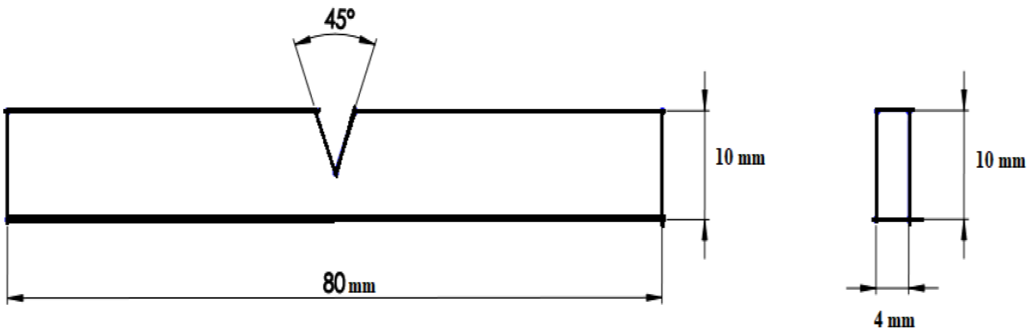

Figure 1. 7 Schematic of the Charpy V-notch specimen according to ISO 179 [12]

The most important part of the CVN machine is the notch knife. Therefore, it is very important that the knife angles are within the tolerance range determined in accordance with the standards to reach correct results. The notch knife is shown in Figure 1.8.

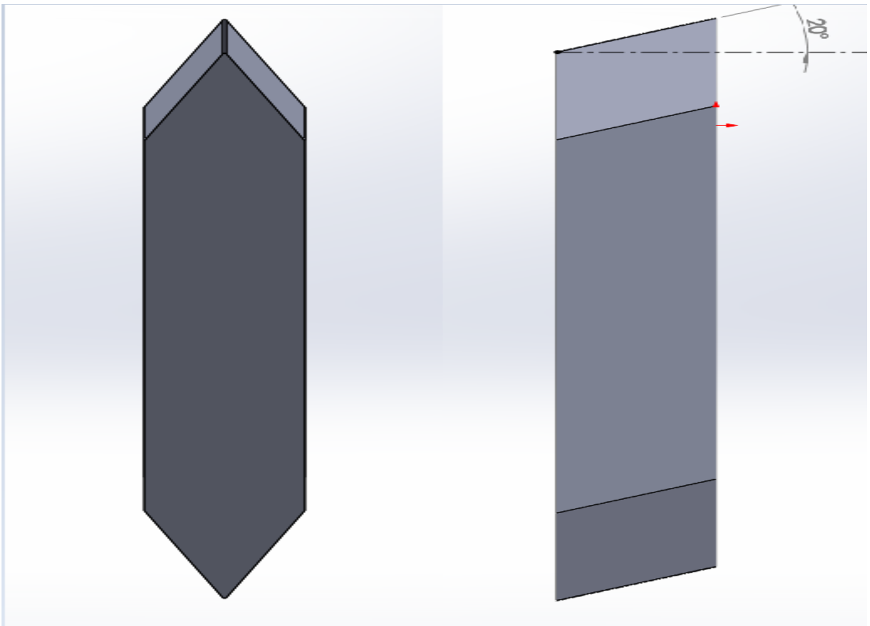

Figure 1. 8 3D model of the notch knife

There are many different designs for the Charpy V-notch machine. General differences between the machines are knife structures and the cutting planes. These differences vary depending on the material to be notched. Some CVN machines use one notch knife, some CVN machines have more than one notch knife.

1.3. Different Design Alternatives

With the developing technology, many different designs have been developed so that the results can be perfect. CVN machines are divided into different categories according to which material notch and its technology. Selection criteria are formed accordingly. These can be grouped into different titles. These are Automatic CVN machine, manual CVN machine, Linear notch knife CVN machine, rotational notch knife CVN machine and multi knife CVN machine. There is a cost difference between an automatic CVN machine and a manual CVN machine. There is a notch quality difference between the linear notch knife and rotational notch knife. Notching cannot be performed on more than 5 specimens at the same time on linear CVN machines. On the other hand, in rotational CVN machines, many parts can be notched at the same time. Although generally similar results are obtained, price and precision are the prominent differences.

1.3.1. Motorized Charpy V-notching machine

A motorized notching machine is used to notch on specimens for the Charpy impact test. Notching operation is performed with the power of the electric motor and the desired depth is obtained using a micrometer. Generally, a motorized CVN machine consists of a vice, knife, motor, and micrometer. Cutting speeds can be adjusted as desired in these machines. Motorized CVN machine has a constant cutting action, which will help improve notch knife life. Likewise, feed rates can be easily changed with software support, or the cutting speed is constant in some designs. It is used to notch multiple specimens. The surface finish and dimensional tolerances of the specimen is better than manual CVN machines since it is constantly cutting with the same power. The main advantage of this machine is that provides the operator to conduct optimal notching conditions for the impact test specimen. One of the disadvantages of motorized CVN machines is the high cost. Motorized CVN machines are divided into two groups according to cutting methods or cutting direction. These are linear knife Charpy V notching machine and rotational knife CVN machine.

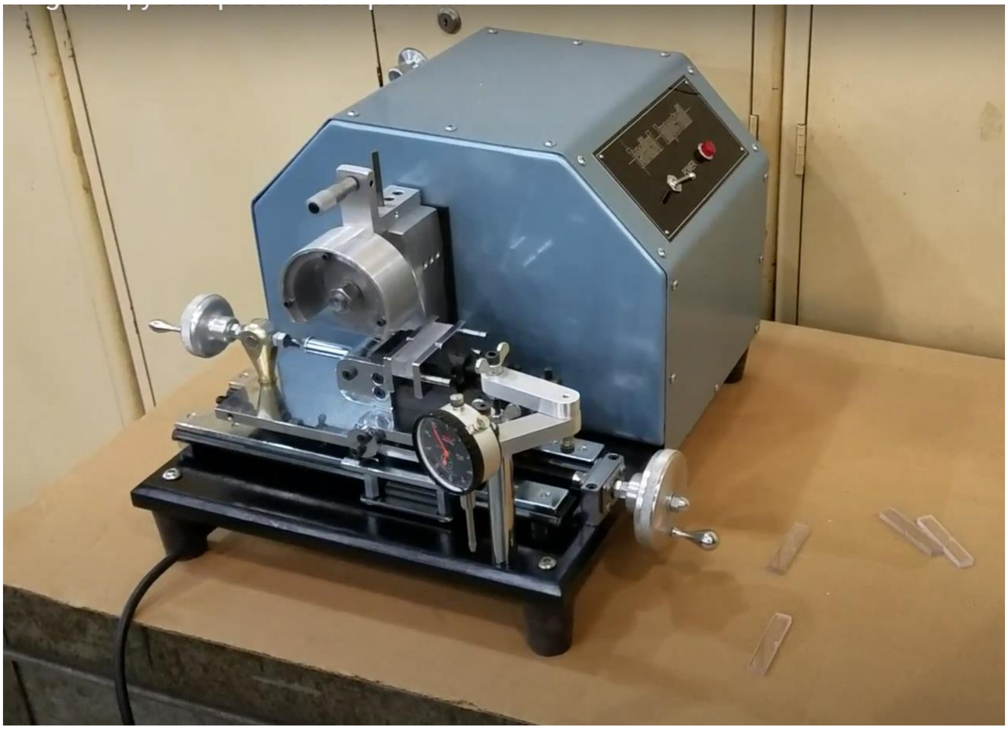

Figure 1. 9 A Motorized CVN machine which belongs to Tensilkut company.

1.3.2. Linear motorized knife Charpy V-notching machine

The main materials of this machine are a micrometer, vise, and electric motor. Rotational motion from the motor is converted into linear motion by the mechanism inside the machine so the knife moves up and down and the notching action occurs in the z direction. The working principle is as follows; after the specimen is placed in the vise, the knife starts to move in the z direction. There is a micrometer behind the part where the specimen is located so that desired depth is adjusted with a micrometer. Specimen moves the x-direction. Generally, multiple specimens cannot be notched at the same time.

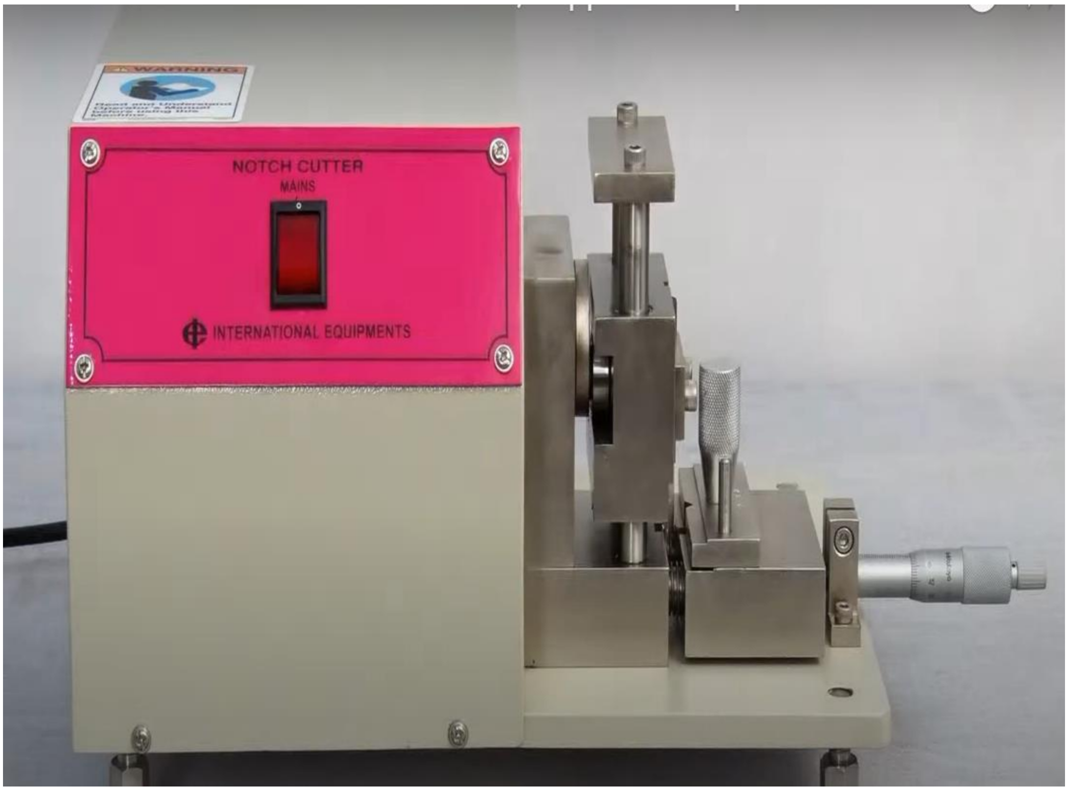

Figure 1. 10 Linear motorized CVN machine which belongs to international equipment.

1.3.3. Rotational motorized knife Charpy V-notching machine

A rotational knife is designed to enable production the sample preparation of the non-metallic material. It consists of two basic moving parts. The part where the specimens are clamped with a vise and the part with the knives. The specimens move in the x direction with the linear guideway. Then the knives are lowered in the z-direction at the desired depth. An operator is needed to adjust the notch depth. Multiple specimens can be notched at the same time.

Some manufacturers produce models in which the vise also moves automatically in the x direction. On most models, the vice is moved manually with ball screws. There are models in the market where the vise moves in both x and z directions instead of the movement of the knife.

Figure 1. 11 Motorized rotational CVN machine.

1.3.4. Hand operated Charpy V-notching machine

Hand operated CVN machine is designed for small batches of test pieces in carbon steels, easily machined low alloy steels and plastic materials. There is a handle on these machines. Rotating the handle, the notch knife is moved so that the notching is completed. In some models, both the handle must be moved and the specimen notched fed at the same time. It can be used with one hand on the current model. Knife feed and planer move simultaneously. Hand operated CVN machine is inexpensive price compared to other models. It is similar to a motorized linear knife Charpy V- notching machine. However, it is produced according to ISO, ASTM standards and it cannot exceed the specified tolerance value.

Figure 1. 12 Hand operated CVN machine

The dual tooth cutting wheels can be used on some designs. It provides to reduce cutter load on the sample being notched. This machine includes a micrometer for adjusting notch depth.

1.3.5. Multi Knife Charpy V-notching machine

Depending on the hardness of the materials used, single tooth knife or a multi tooth knife are used. A multi knife is used for materials that are harder to notch. These machines are used for carbon steel and low alloy steel. Broaches are used with multiple knifes. The notch is made by manually moving the knives up and down in the z direction. One of the advantages is that both u and v notches can be made on the specimen simultaneously using multi notch attachments.

Figure 1. 13 Broaching CVN machine

1.4. Polymeric Pipeline Materials

Plastic materials have replaced many materials. There are many types of plastic materials, and plastic materials are produced from polymers. Polymers are long chain structures formed by the joining of monomer molecules by chemical bonds. Polymers are divided into 3 main groups as plastics, rubbers, and fibers. Polymers are highly preferred as building materials. They are preferred because they are light, easily shaped and high mechanical strength. There are natural and synthetic polymers. Synthetic polymers are produced in a laboratory environment with petroleum-based materials, such as polyethylene, Bakelite, PVC while natural polymers are inherent in nature, such as DNA, cellulose, and wool.

Synthetic polymers are divided into 3 groups: thermoplastics, thermosets, and elastomers.

Thermoplastics are highly preferred. These are materials that can be easily shaped by heat and can be shaped repeatedly after cooling. Polyethylene and polypropylene are the most common examples of thermoplastics. Thermoset plastics are highly resistant to heat and cannot be reworked or shaped. Polyurethanes are the most common example. They are similar to thermoset plastics with elastomers and the most important properties are flexible and elastic. Polybutadiene and polyisoprene are the most typical elastomers.

Polyethylene is a durable and chemical resistant engineering plastic used in various products. Polyethylene used in many different sectors are the main areas of use in chemical tanks, pipes, automotive and kitchenware. It can be divided into various classes according to their density and chemical properties. It has high density and low-density polyethylene. LDPE (low-density polyethylene) is more used for covering plastic bags, packaging and packaging stretch films, cables. HDPE has high strength and high resistance to many different acids and other gases. It is much stronger than LDPE. used for storage containers, industrial parts.

Polypropylenes have a wide range of uses, from the automotive industry to textile materials. PPRC made using polypropylene material is widely used in the pipe industry.

1.4.1. HDPE

High Density Polyethylene (HDPE) is a type of thermoplastic whose main component is petroleum. HDPE is used in many different areas such as plastic bottles, shampoo bottles, bleach bottles, and pipes. HDPE has high impact resistance. HDPE can be easily meltable and moldable. It has very high resistance to chemicals. There are some benefits of HDPE. HDPE bottles are recyclable.

The mechanical properties of HDPE pipe material seen in figure 1.14 taken from [17]

Mechanical Properties at 23 °C

PROPERTY	UNIT	VALUE / RANGE
Tensile Strength, Yield at 23 C	MPa	23.0 - 29.5
Tensile Strength, Break at 23 C	MPa	30.5 - 33
Elongation, Yield	%	9 - 18
Elongation, Break	%	600 - 1350
Tensile Modulus at 23 C	MPa	900 - 1550
Flexural Strength, Yield	MPa	
Flexural Modulus	MPa	970- 1380
Compressive Strength	MPa	
Izod Notched	J/m (kJ/m^2)	71 - 159 (20)
Izod Unnotched	J/m	No Break

Figure 1. 14 Mechanical Properties of HDPE [17]

1.4.2. PPRC

Polypropylene random copolymers are thermoplastic resins produced by combining propylene and ethylene. PPRC (polypropylene random copolymer) is highly durable material at high and low temperatures and variable pressures. It is frequently used as a cold water and hot water pipe due to its high level of durability. It provides good thermal properties. The inner surface of PPRC pipes is smooth to ensure fluidity. It has high resistance to chemicals and can be used for many years.

The mechanical properties of PPRC pipe material seen in figure 1.15 taken from (Fırat Boru Company)

Property		Unit	Test Method	Value
Density	+23C	g/cm3	ISO 1183	0,909
Melting Flow Rate	MFR 190/5 MFR 230/2,16 MFR 230/5	g/10 min g/10 min g/10 min	ISO 1133 ISO 1133 ISO 1133	0,55 0,30 1,20
Volume Flow Rate	MFR 230/2,16	cm3/10 min	ISO 1133	0,4
Tensile Strength	(50 mm/min)	MPa	ISO 527/1+2	25
Elongation Rate	(50 mm/min)	%	ISO 527/1+2	600
Shore D Rigidity	(3 sec value)		DIN 53505	65
Charpy notch (Resistance)	+23°C 0°C -30°C	kJ/m² kJ/m² kJ/m²	ISO 179/1eU ISO 179/1eU ISO 179/1eU	43 43 43
Charpy Notch Impact Resistance	+23°C 0°C -30°C	kJ/m² kJ/m² kJ/m²	ISO 179/1eA ISO 179/1eA ISO 179/1eA	52 7 2,5
Vicat Softening Point	VST/A/ 50 VST/B/	°C °C	ISO 306 ISO 306	132 69
Melting Interval		°C	DSC	150-160
Linear Thermal Expansion Co-efficient		1/K	DIN 53752	0,030
Thermal Conductivity		W/mK	DIN 52612	0,24

Figure 1. 15 PPRC mechanical properties [18]

1.5. Literature Survey and Selection Criteria

Test standards have been introduced to eliminate confusion because tests performed in many areas of the world are not similar. There are two standard sources to determine for CVN machines, these are ISO and ASTM. ASTM (American Society of the International Association for Testing Materials) was established in 1898 and its purpose eliminates the problems encountered in the industry by developing better standards. ISO (International Standards Organization) is an organization that prepares international standards on all subjects except electrical and electronic issues. These standards are valid for CVN specimens. The specimens should be produced in accordance with the standards. In 2012, in the study carried out by Ömer ERKENDİRCİ, he worked on the effect of the thickness of the specimen on the impact results. As a result of the study, the thickness of the specimen affects the Charpy impact results, and the impact toughness increases with the increase in thickness [2]. For which material impact test will be performed, the required standards will be based on the material in order to be notched appropriately.

Previously, the test specimen was prepared in the form of a flat rectangle without a notch. In 1892, a notched specimen was started to be used for this experiment. There are lots of methods for the machining of the notch such as grinding, broaching, and milling. In another study in 1990, the effects of the preparing method for the impact notches were examined. At the end of the study, it was obtained, there is not much difference between the two methods, and it is accepted that both broaching and grinding method can be used for notching the Charpy specimen and it is a slightly more advantageous method than the grinding methods [3]. Broaching to produce notch is faster and it is mostly using for metallic materials. Single-tooth cutters preferred because it cuts specimen more easily and leaves a smoother surface.

In another study in 2012, the effects of the sample pre-cracking method and notch geometry on PMMA (Polymethyl methacrylate) resin were examined, PMMA is a kind of thermoplastic, and two methods were used one of them is tapping on a blade and the other one is pressing blade. Disc rotated 3600 rpm in tapping on a blade, as a result of the study, the change in polymer behavior in the tapping on a blade method is less than in the pressing blade method so that tapping on blade method preferred for the PMMA.[4]

In addition, notches can be created using contact and non-contact techniques. In contact notching machines, an operator is generally needed to adjust the depth of the notch. Non-contact notch techniques depend on the operator. The femto- laser technique can be shown as an example for the non-contact and the broaching is a contact technique. Another study in 2013, it was studied the effect of the different notching techniques, as a result of this study, contact techniques produced larger cracks than non-contact and as a result, the fracture toughness value increased. [5]

The most critical part of the Charpy impact test is the notch so that the main focus of CVN machine design is the notch. In another study in 1996, as a result of the study, it has been mentioned that notch depth, notch root radius and notch angle affect the Charpy impact results and DBTT depends on the notch depth [6]. Therefore, it is very important for the test results that notch angles are produced within the specified standards and tolerance range.

A similar study in 2016, it was studied on hybrid composites related to notch angle effect, as result of the study the notch angle affects the absorbed energy, and that when the notch angle increases between the 45° and 75°, the absorbed energy decreases. [7]

Metal can be ductile at a certain temperature, and it becomes brittle at another temperature. This is the Ductile-to-brittle temperature. DBTT is measured by the energy absorbed in the Charpy impact test. Another study in 1993, it was studied the effects of the V-notch dimension for the miniaturized specimen. Research shows that the ductile-to-brittle transition temperature (DBTT) and the upper shelf energy (USE) depend on notch depth [8].

As a similar study shows, it was studied that the effect of specimen size and notch geometry on impact test results on vessel steel A533B, as a result of the study, DBTT depends on both notch depth and notch root radius, DBTT is increased when the notch depth increases or notch root radius decrease. [9]

Three different types of notches with tolerance values are shown in Figure 1.14.

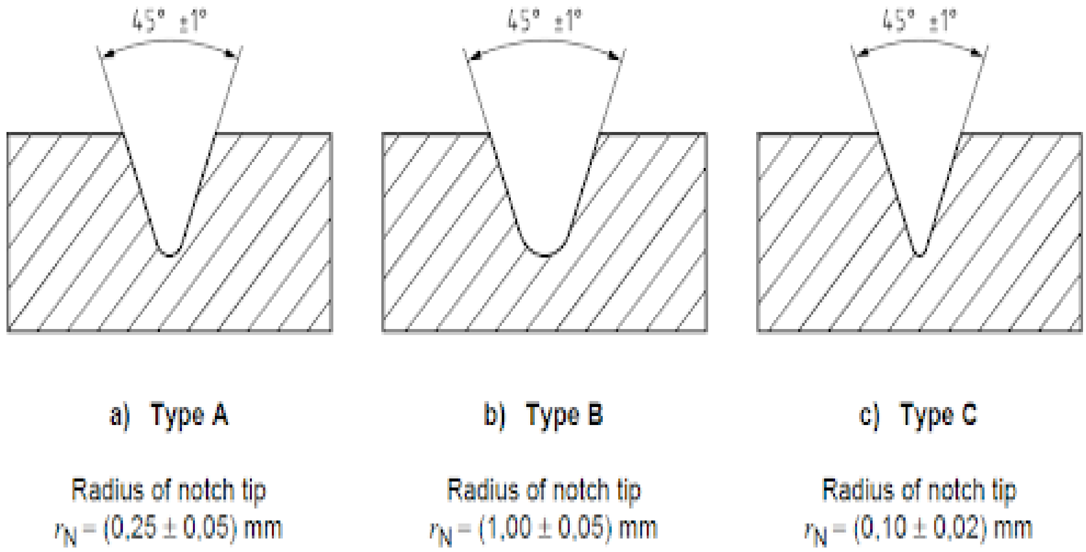

Figure 1. 16 Notch root radius according to ISO 179

Cutting tool steel or carbide-tipped cutter is generally used as it is loaded in the notching process. According to ISO 2818:1996 [10], the diameter of the cutting tool can be between 60 mm to 80 mm and the number of teeth is 1 for the thermoplastics.

During the notching process, both thermal deformation and stress are seen in the specimen, so specimen cutter speed and feed rate is important for the Charpy impact test.

According to ASTM D6110-04, high cutter speed with a low feed rate cause more thermal damage than the lower cuter speed with a high feed rate so the cutter speed can be 54 to 150m/min and the feed rate can be 89 to 160mm/min [11]. According to the ISO2818:1996 [10], the plastic material notch method of machining is medium-speed milling and the rotational speed of the can be between 200 to 1000 rpm. The cutter speed and feed rate should not change during the notching to avoid thermal deformation.

One of the aims of this thesis is to manufacture a CVN machine that adopts low or medium speed. It does not make sense to choose the multi knife CVN machine because the material to be notched is plastic. Although multi knife CVN machines can be used for plastic, they are more expensive than other CVN machines and it is often used for the metallic material. Linear CVN machine or rotational knife CVN machine is more suitable for this thesis because it is both economical and relatively easy to design. CVN machines should not deform the specimen during the notching process. Considering these, since cutting speed cannot be adjusted on hand operated CVN machines, motorized is preferred. In linear CVN machines, an extra mechanism is required as the circular motion from the motor must be converted into linear motion. Therefore, rotational CVN machine design is easier than linear knife CVN machine.

The second most important part is the design of the multiple specimen notch. In the models of linear CVN machines that can be produced cheaply, more than one specimen cannot be notched at the same time. The most suitable machine is the rotational knife CVN machine for this.

Figure 1. 17 Multiple specimen notching

Notching specimens at high speed may cause stress by causing damage to the internal structure and errors to occur in the result. Cutting speed should remain constant while notching the specimen. Considering these, the design and production of the rotational CVN machine will be made within the scope of this thesis.

1.6. The Purpose and Originality of design

Rapidly increasing production has enabled much new material and new methods to be found. It is observed that the material used in industrial applications is damaged according to the ambient temperature and the type of load applied. Engineers consider these criteria when choosing materials. Companies need experimental methods to check the safety and quality of their products. One of these tests is the Charpy impact test to determine at what temperature the materials are ductile and what temperatures are brittle. In order to perform the Charpy impact test, the specimen must be notched. In this thesis, rotational CVN machines will be designed and manufactured adhering to the required standards.

This thesis study is about making a functional prototype by designing rotational CVN machine for using plastic materials. One of the main focuses of this thesis is to produce low a cost rotational CVN machine that can be used as an alternative to other CVN machines. This CVN machine, which is planned to be produced and designed, will use a threaded rod and linear bearing mechanism instead of adjusting the notch depth with a micrometer. The movement of the knife will automatically notch with the help of the motor instead of the handle operation. Instead of the steel body used in the commercially available CVN machines, a cheaper cost body design was made. An inexpensive motor with adjustable speed will be used.

2. MATERIAL AND METHODS

‘SolidWorks 2016’ was used as the design program in all stages of this study. Many mechanical parts were used in the production and design of this rotational machine and motor was used as an electronic part. The designed and manufactured machine moves in the x and z directions but not y direction. Axial movements in the machine are used in two different designs. SBR 16 UU, which moves on Ø16 mm chrome plated bar as a linear bearing, is used for the movement in the z direction. A threaded rod is used which allows the motor to move 1 mm in z-axis movement when it rotates once. On the other hand, a linear guideway is used, which allows the specimen to move in the x direction. Movement is provided with a threaded rod and nut. A sewing machine motor powered by 220-volt electricity is used to move the knife. Motor and linear bearings are connected by sheet metal. A dimmer is used to adjust the rotation speed of the motor. Thus, it can be used at any desired values up to 7000 rpm.

2.1. Linear Rails and Blocks

Linear Rail system is designed to transmit the motion of a load linearly, both vertically and horizontally. It is often one of the best ways to move the load with as little friction as possible when it needs to be moved to another location. Many names are used for this system such as linear guideways, linear slide mechanisms or linear rails. High positional accuracy, high speed motion with low force, easy installation, easy lubrication are among the main advantages.

Figure 2. 1 Linear guideway system

2.2. Miniature Pillow Blocks

A miniature pillow block is a bearing that requires a lower load. Bearing is a machine part that prevents sliding friction by providing rolling friction and reducing energy losses. Usage areas of miniature pillow blocks are 3D printers, electric motors and machine which require low load.

Figure 2. 2 Miniature pillow blocks

2.3. Chrome Plated Bar

It is the machine parts that help bearings run on a clean surface. The chrome plated bar also helps extend the life of the bearings. It is used with linear bearings.

Figure 2. 3 Chrome bar

2.4. SBR Linear Bearings

Linear bearing is a machine part used for movements on a linear plane. Linear bearings are parts that help move a load to another place. Friction is reduced, thanks to the balls inside. SBR 16 UU linear bearing is used.

Figure 2. 4 Linear bearing

2.5. Threaded Rod

Threaded rod, often called as a stud, have variable size. It is designed to be used under tension. Generally, it is used as a fastener machine element, and it can be used in rotational movements thanks to its thread. Ø8 mm and Ø10 mm threaded rod is used.

Figure 2. 5 Threaded rod

2.6. Vise

It is a tool that allows the workpiece to be tightened with the help of a lever and processed on it. There are many vices according to the purpose of use, such as bench vise, hand vise, machine vise.

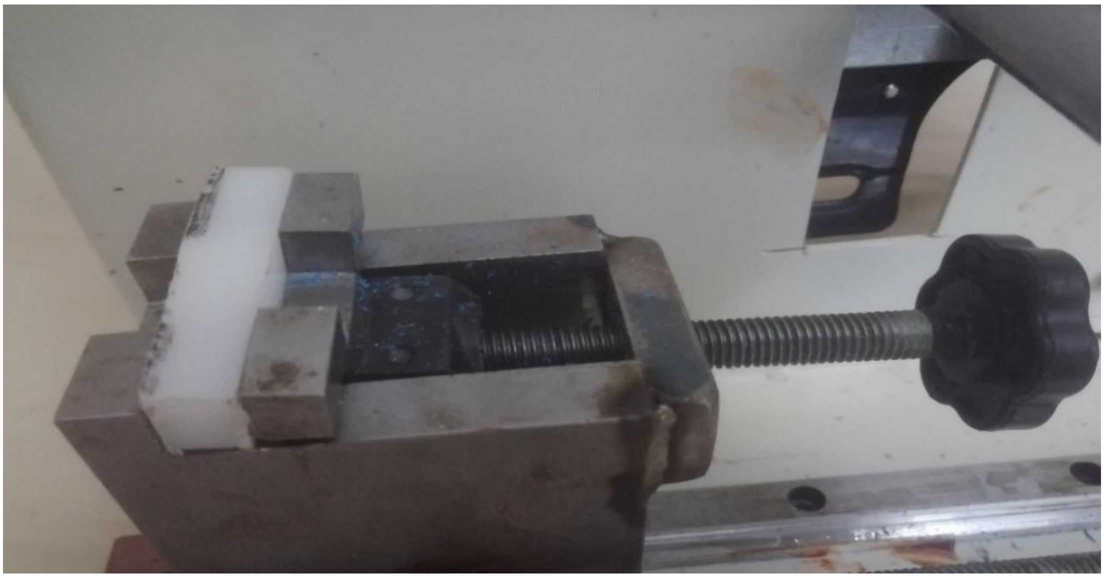

Figure 2. 6 CVN machine vise

2.7. Caliper

Caliper is a precision measuring instrument. The caliper is used to measure inside diameter, outside diameter and depth as well as a length measurement.

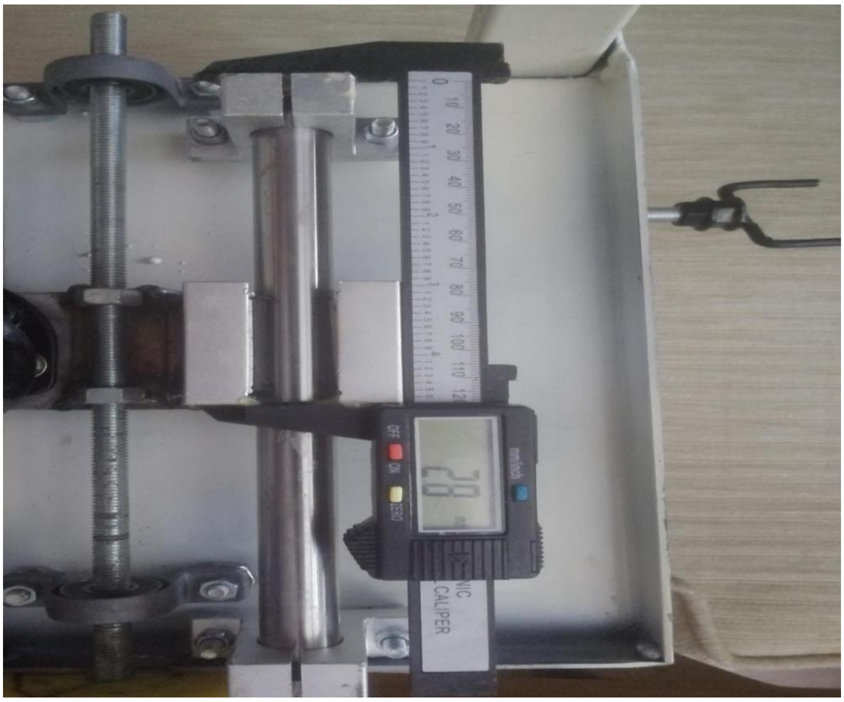

Figure 2. 7 Caliper

2.8. Sewing Machine Motor

A sewing machine motor is used because of its lightness. AC 220 V, 50/60 Hz frequency, 130 W and it can rotate up to 7000 rpm.

Figure 2. 8 Sewing machine motor

2.9. Dimmer

It is generally used for brightness adjustment in lighting systems, but the working principle is the same as a potentiometer. It is a manually adjustable resistor. The incoming electric current can be adjusted as desired by increasing or decreasing the resistance.

Figure 2. 9 Dimmer

2.10. Knife adapter

It connects to the motor shaft and transmits the incoming power the blades tightened with screws. It provides the connection and strength between the cutting tool and motor. It ensures stable operation by reducing the stress between the motor and the blades. It is suitable for 8×10 mm cutting tools.

Figure 2. 10 Knife holder

2.11. Charpy V-Notching Machine Designing and Assembly Stages

2.11.1. X axis design and assembly

The part that moves in the x-axis is the specimen. There should be a design in which the linear motion is transmitted to the specimen. In addition, a vise is required to place and vise multiple specimens. Linear rails and blocks, 2 miniature pillow blocks and Ø10 mm threaded rod are used in the motion transmission in the x-axis. Abba BRD15R0 linear block with a width of 34 mm and length of 56 mm is used and the length of the linear rail is 320 mm.

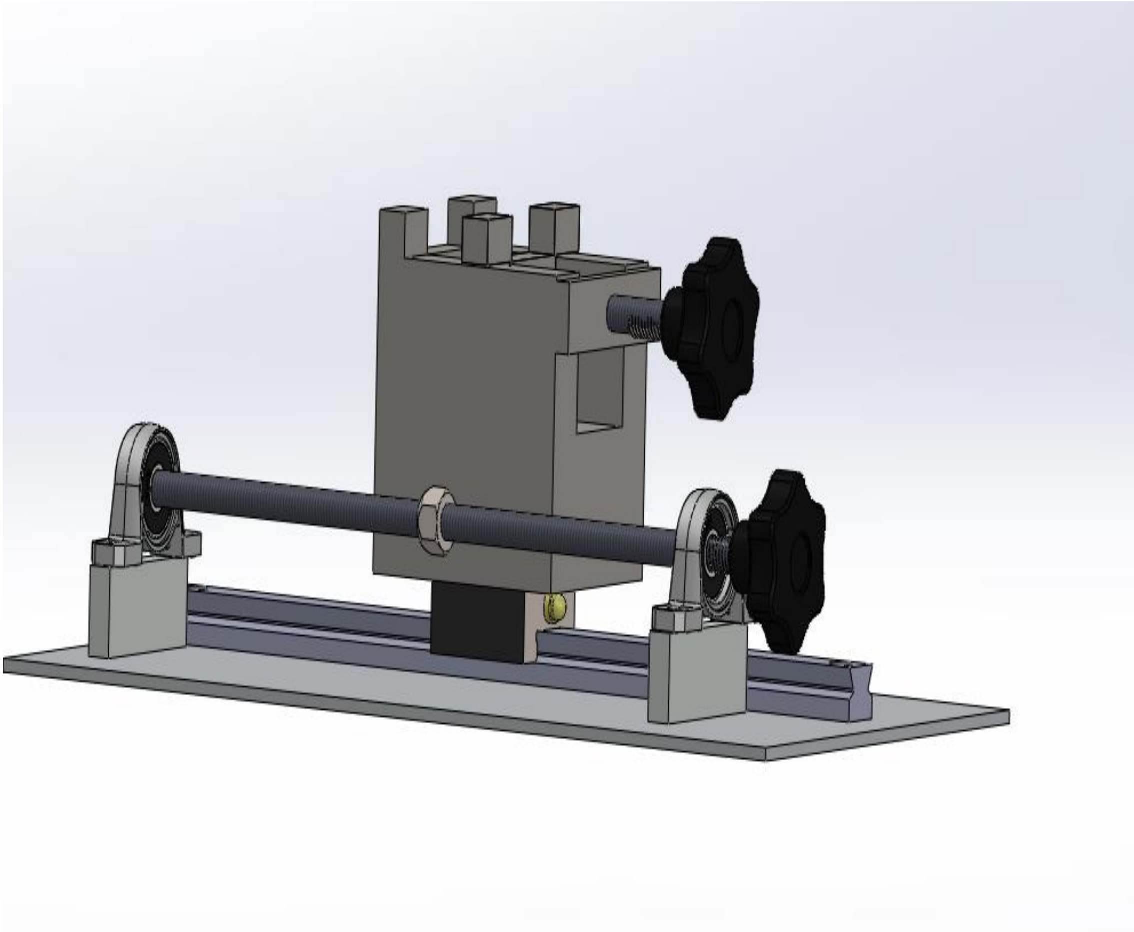

Figure 2. 11 3D model of x-axis

The vise made of steel material is 55 mm wide, 70 mm high and 70 mm long. 3 mm thick aluminum sheet with a length of 330 mm and a height of 300 mm is used as the body material in the x-axis.

In this design, the fed rates of the specimens are controlled by means of threaded rods and the notching process is controlled. The vise or the specimen moves 1.25 mm on the horizontal axis when threaded rod rotates once. In this way, the specimens are prevented from being exposed to sudden impact and it affects the surface roughness. In addition, the load on the knives is taken under control.

Vise and linear blocks are mounted to each other. Then, the linear rail and aluminum sheet are mounted to each other. The nut is welded to the vice and the interconnected parts are made movable with the help of threaded rods and miniature pillow blocks. U-shaped apparatus is used instead of a star knob for easy rotation. The difference between the miniature pillow blocks and linear guideway heights is closed by mounting an additional piece under the miniature pillow blocks.

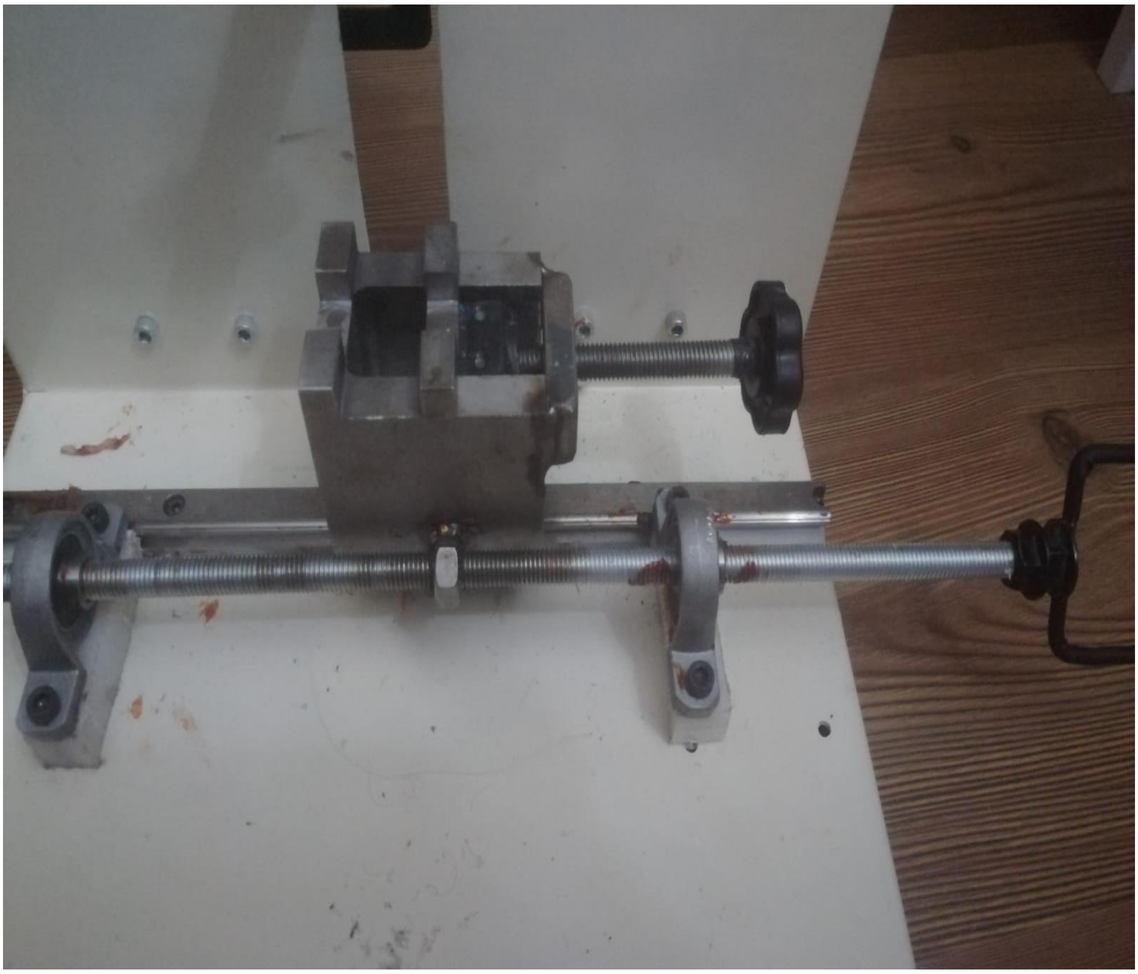

Figure 2. 12 After assembly of x-axis

2.11.2. Z axis design and assembly

The depth of the sample notches will be adjusted by moving the motor up and down on the z axis. The system is designed considering that the desired depth is sensitive, and that system should carry the motor. 2 SBR 16 UU linear bearing and thread rod are used for motion transmission in the z axis. The threaded rod is Ø10 mm in diameter and the pitch is 1 mm. 3 mm aluminum sheet is used as the z-axis body material. In order to adjust the desired depth, a scale divided into 4 equal parts and a marked handle are used. 3D drawing of Z axis is shown in Figure 2.13.

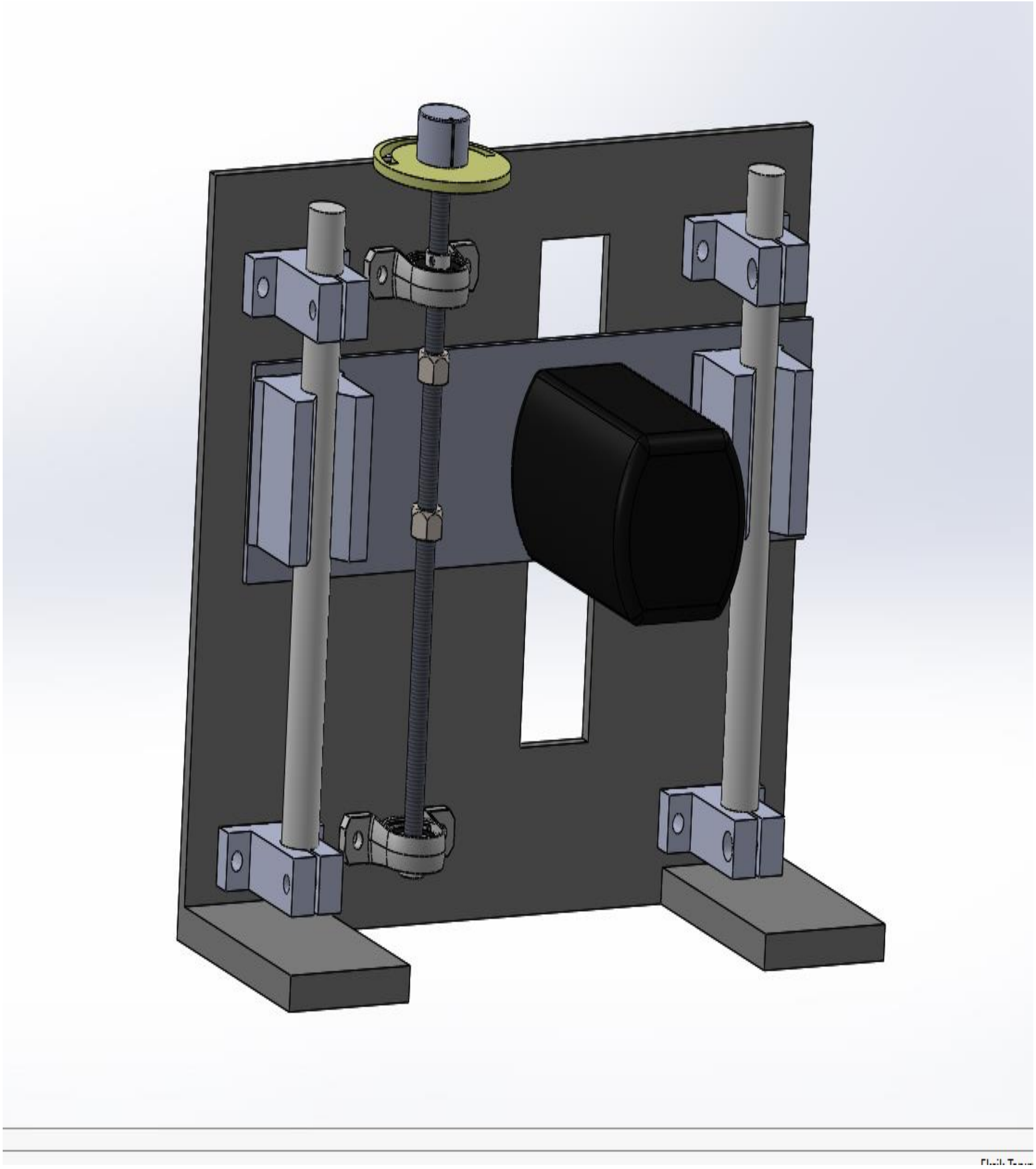

Figure 2. 13 3D model of Z axis

Plastic material is designed to reset the scale after the knife touches the specimen is shown in Figure 2.14. After the knife touch the specimen, the plastic part is set to 0. The distance between each bar on the scale is 0,25 mm. Since the plastic specimen depth is 2 mm, the knob is rotated 2 when the knife touches specimen.

Figure 2. 14 Depth adjustment scale system

A piece of 80 mm length and 15 mm width was cut from the body for the up and down movement of the motor in the z-axis. 5 mm thick aluminum sheet and 2 linear bearings were mounted together, then 2 nuts and aluminum sheet are welded together. 2 linear bearings and chrome plate are mounted to 3 mm thick aluminum sheet with bolts. In the same way, 2 miniature pillow blocks and an 8 mm threaded rod are mounted according to nut position. Finally, the motor is mounted on the sheet.

Then, in addition to the scale system, a digital caliper is added to adjust the depth. It is mounted between the linear bearing and 5 mm sheet metal as shown in Figure 2.15.

Figure 2. 15 After assembly of z-axis

2.11.3. Notch knife and electric motor

A knife adapter is used to transmit the power from the motor to the knife. Dimmer is used to adjusting the rpm of the motor. The motor can turn 7000 rpm at maximum power and its power is 100 watts.

Square 8 mm tool steel is used as the cutting tool. Knife with radii of 0.1 mm, 0.25 mm, 0.5 mm, and 1 mm is produced. In order to reduce the moment of inertia on the knife, the knife tip has a 20° rake angle.

Figure 2. 16 Cutting tool.

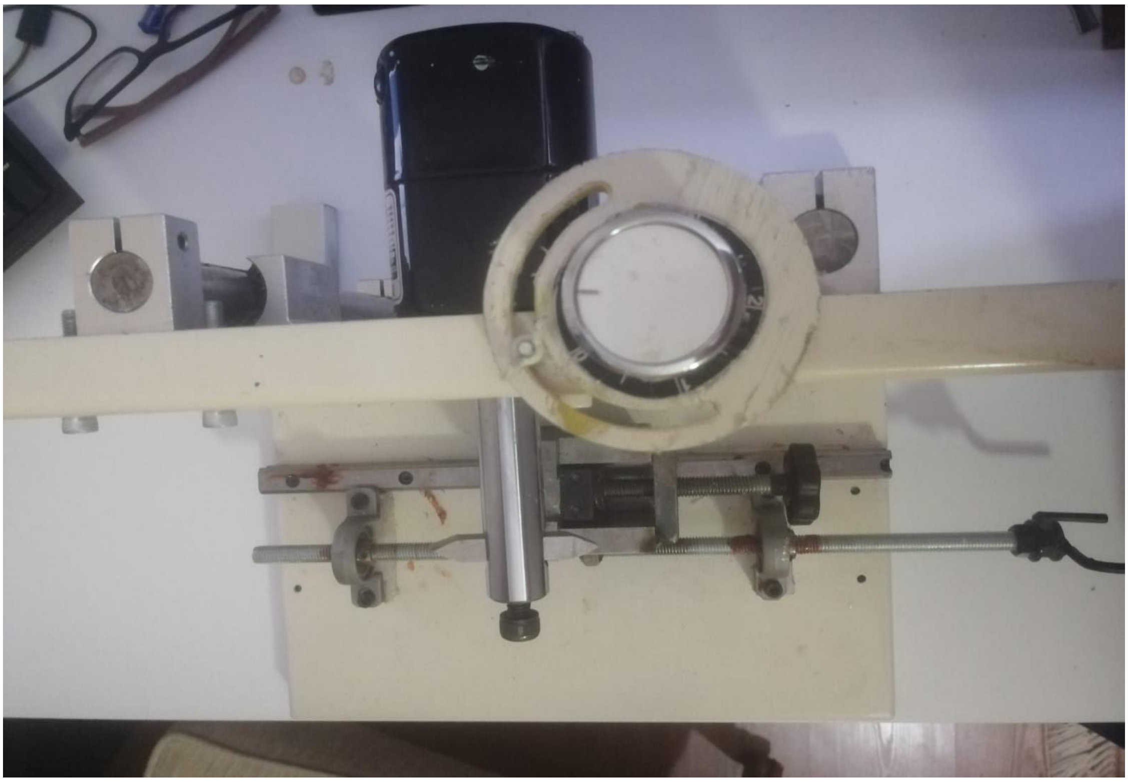

Figure 2. 17 Final Assembly of Charpy V- notching machine

2.12. Specimen Preparation

Test specimen can be machined from the material plates or sheets**.** If there is none, it can be done by injection molding or compression molded method within the determined standards. If the material from which the specimen is prepared is not smooth, it is done by processing the piece cur parallel to the main axis.[10]

In this study, both HDPE and PPRC specimen to be used for notching were taken from the pipe wall. Firstly, pieces were cut longitudinally from the pipes. In order to reduce their thickness, they were passed through the planer machine longitudinally and only one surface was processed. Then the desired specimen was created by using the mold in the press machine for the desired length.

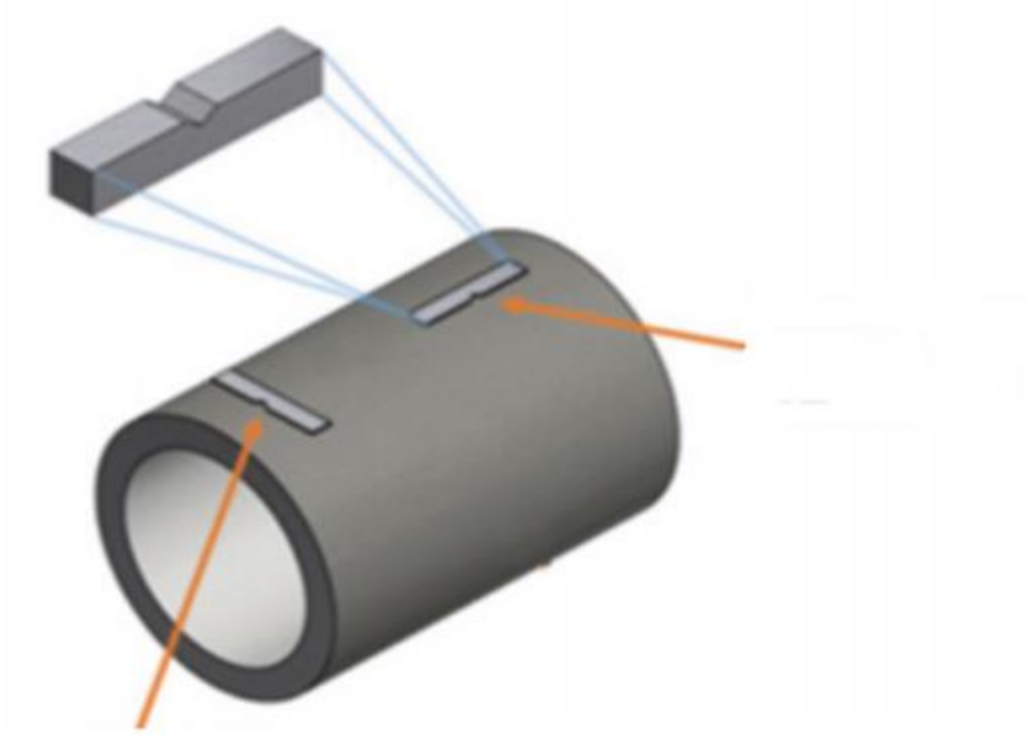

Figure 2. 18 Preparation method of specimen from the pipe [19]

3. RESULTS AND DISCUSSION

3.1. Notch Depth Test

The notch depths are checked to measure the precision of the notches in the Charpy notching machine. The samples produced according to the plastic standards are notched. This test has been done for both polyethylene and polypropylene. In these materials, 0.1 mm, 0.25 mm, 0.5 mm, and 1 mm deep notches with.

It is aimed to give these materials a 2 mm deep notch with a radius of 0.1 mm, 0.25 mm, 0.5 mm 1 mm.

2 polyethylene samples are clamped in a vise, and a total of 8 polyethylene samples are notched. 2 polypropylene samples are clamped in a vise and a total of 8 polypropylene samples are notched.

Figure 3. 1 Polypropylene sample after notching with 1 mm radius.

Figure 3. 2 Polyethylene sample with 0,1 mm radius

The results from the test results are given in table 3.1 and table 3.2.

Table 3. 1 Polyethylene specimen notch depth results

Polyethylene Specimen				
Sample Number	Notch depth (mm)			
	0.1 mm radii	0.25 mm radii	0.5 mm radii	1 mm radii
1st sample	2,13	2,36	2,71	3,11
2nd sample	2,15	2, 33	2,79	3,16

Table 3. 2 Polypropylene Specimen notch depth results

Polypropylene Specimen				
Sample Number	Notch depth (mm)			
	0.1 mm radii	0.25 mm radii	0.5 mm radii	1 mm radii
1st sample	2,04	2,11	2,48	2,79
2nd sample	2,05	2, 09	2,55	2,74

According to ISO 179, notch base radius must be 0,25±0,05 for A type, 1,0±0,05 for B type and 0,1±0,02 for C type. A and C type notches in polypropylene specimens are very close to the tolerance range but polyethylene materials are far from these tolerance values. After intensive use, it is necessary to check whether the same results are achieved. According to ISO 12818:1996, after every 500-specimen notched, it should be examined whether the desired contour is acceptable.

As can be seen from the results, as the radius of the knife increases, samples are formed at a greater depth than the desired notch. It is seen that the knife with a radius of 1 mm have the most depth since the surfaces in contact with specimen is more than the other knife. Lower radius knife should be preferred in future notches.

On the other hand, samples on the same vise have different depths as seen from the values. One of the main reasons for this may be due to the different tolerance values of the samples. The height tolerance will be transferred to the notch depth if there is more than one group of samples lined up together. It should be preferred not to use more than one sample for notches in the future.

3.2. Impact Test

In this study, the impact test was performed on HDPE (High density polyethylene) and PPRC (polypropylene Random Copolymer). Instron CEAST 9050 in our university's laboratory was used. A total of 12 HDPE samples were prepared in groups of 3 with 4 different radii. In the same way, a total of 8 PPRC samples were prepared in 2 groups with 4 different radii. The average break energy of specimens is given in table 3.3.

Table 3. 3 Impact test results of HDPE

Notch Radius	Break Energy [J]			
	Specimen 1	Specimen 2	Specimen 3	Average
0,1 mm	0,231	0,182	0,264	0,226
0,25 mm	0,568	0,627	-	0,598
0,5 mm	0,712	0,603	0,702	0,672
1 mm	0,491	1,178	-	0,834

In a study conducted in 2012, it was observed that the absorbed energy decreased when the thickness of the specimen remained constant, and the notch depth increased and the notch root radius of the specimen was 0,1mm [12]. When I compare it with my thesis work, especially in the specimen with 1 mm notch root radius as can be seen in the table 3.3, I can say that the notch depth given in 1st specimen is quite high compared to 2nd specimen. Since there was no such difference between the lengths of the samples, it was possible that the vice lifted the first sample during notching. Difference in other notch root radius may be due to difference in tolerance values.

As can be seen from the results in table 3.3, the break energy increases as the notch depth increases. Especially, the standard deviation of 2 specimens with a 1 mm radius is higher than the others. It is seen that the notching machine at a depth of 1 mm, where the blades are exposed to more impact, it cannot give the correct notch depth. The knife radius to be used in the future should be considered according to these results. Break energy difference between the sample is about notches depth.

According to ISO 179-1:2000, Charpy impact toughness of notched specimens is calculated using the following equation:

$$a_{cN} = \frac{E_c}{h \times b_n} \times 10^3 \tag{3.1}$$

E_c : is the corrected energy, J.
h : is the thickness of the specimen, mm.
b_n : is the remaining width after the notch, mm.
a_{cN}: is the impact strength of the specimen, $\frac{kJ}{m^2}$

Table 3. 4 Charpy Impact Strength of HDPE

Notch radius (mm)	Impact Strength (kJ/m^2)			
	Sample 1	Sample 2	Sample 3	Average
0,1	21,962	17,938	21,920	20,607
0,25	35,616	39,450	-	37,533
0,5	45,934	38,094	44,774	42,934
1	35,472	73,615	-	54,544

Charpy impact strength results are given in Table 3.4. The impact toughness of high-density polyethylene materials depends on the purity and other composites in it. In study in 2018, mechanical properties of HDPE and LDPE is examined. As a result of the study, the samples were notched according to ISO 179 and % 100 HDPE sample had 35,7 kJ/m^2. %60 HDPE-%40 LDPE had 55.2 kJ/m^2. It was observed that the impact strength increased as the LDPE ratio increased. [13] When I compare it with my thesis work, almost the same value is reached for the 0,25 mm notch root radius specimen for the %100 HDPE material as can be seen table 3.4.

In another study conducted in 2008, metal-polymer mechanical properties are investigated. As a result of the study, in the Izod impact test performed according to ISO 180, the impact toughness of %100 HDPE was 16,73 kJ/m^2. HDPE mixed with %5 Fe powder had 10,08 kJ/m^2 and it was observed that the impact toughness decreases as the Fe powder density increases. [14]

As seen in the above studies, the importance of the components in the mechanical behavior of HDPE has been emphasized. Since the purity rate of the HDPE sample used is not known, making a one-to-one comparison with the above studies may yield incorrect results. The HDPE specimen that I used in my thesis was prepared by cutting from the pipe. Therefore, studies in the literature were examined and compared with the Charpy impact properties of two pipeline materials at room temperature study conducted in 2018. In this study, Charpy impact test results of the two pipeline materials are investigated. One of them is HDPE. 3 samples were notched according to ISO 179-1. As a result of the test, Impact strengths are 40 kJ/m^2, 35,9 kJ/m^2, 56,1 kJ/m^2 with an average 44 kJ/m^2. Notch root radius used is 0,25 mm. In the same study, the absorbed energy was examined. Absorbed energies are 1.28 J, 1,18 J and 1,89 J for the 3 specimens [15]. The values shown in table 3.4 have averaged 37,533 kJ/m^2 impact toughness at 0,25 mm notch root radius. When compared with the study in the literature, it is seen that there are similarities between the results. Based on these results, there is a possibility that CVN machine can be used in HDPE materials for 0,25 mm notch root radius. In order to make a more accurate comparison, the test results made in the factory where the pipe is produced or the results of the company where the HDPE material is produced are required.

According to those results, the specimen with 1 mm, which is notched with the CVN machine produced in this study, shows higher impact strength than the other notches. Notch depth and impact toughness are directly proportional. Differences in impact toughness are clearly seen between specimens with a 1 mm radius. It can be seen that there is a notch depth difference between the two specimens. The total absorbed energy is related to the notched depth. In addition, when I compare the absorbed energy of the 0,25 mm notched specimen shown in table 3.3 with the literature, the average absorption energy obtained from the samples in my thesis is 0.598 J, while this ratio is 1.45 J in the literature. As the notch depth increases, the absorbed energy decreases [12]. Accordingly, we can say that the notches opened in my thesis are slightly more than the depth of the notches in the literature.

Polyethylene samples broken at the end of the impact test are shown Figure 3.3.

Figure 3. 3 After impact test of HDPE specimen

PPRC specimens broken at the end of the impact test are shown in Figure 3.4.

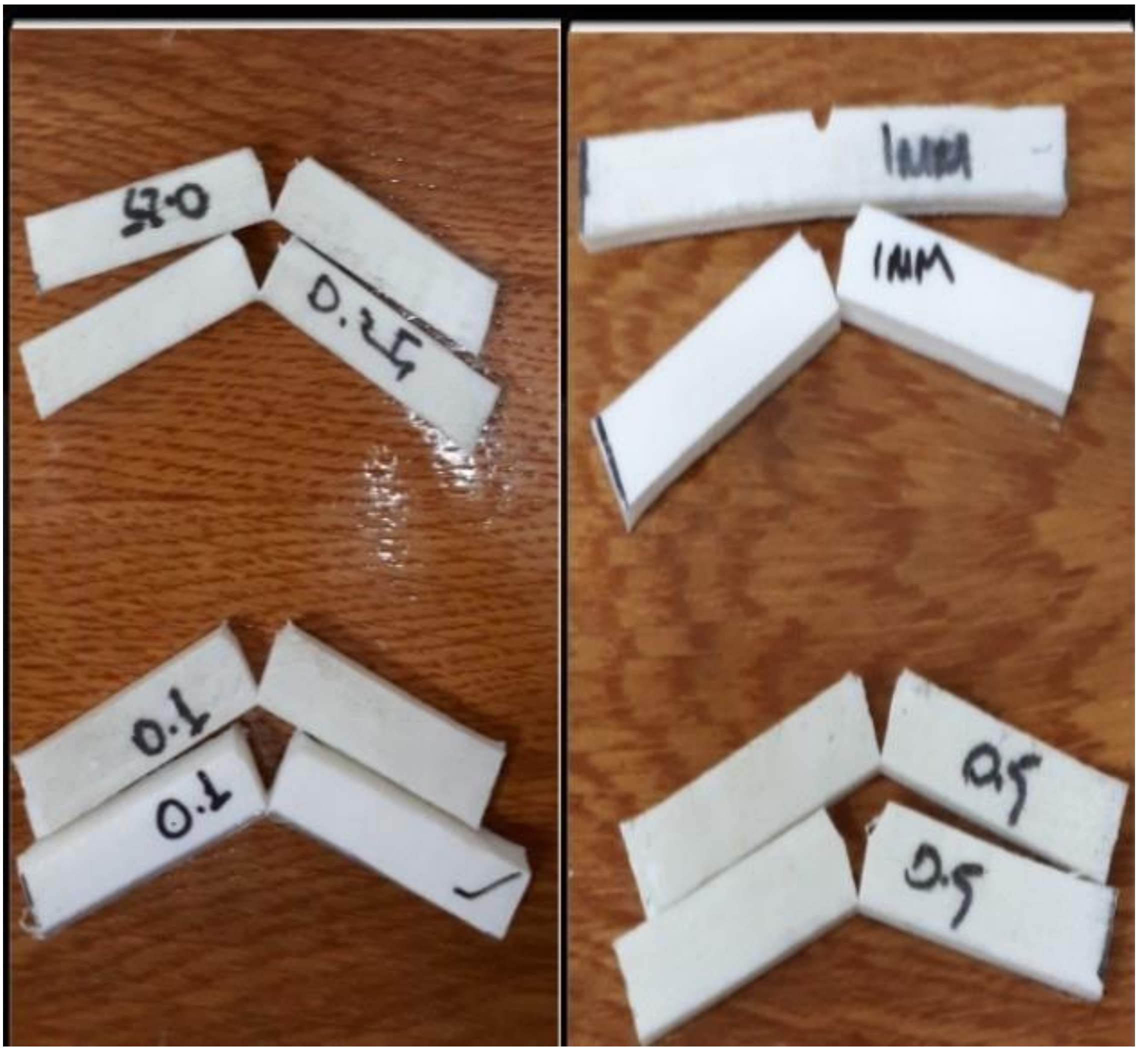

Figure 3. 4 After impact test of PPRC specimen

As seen in Figure 3.4, the first of the 1 mm radius PPRC specimen is not broken and the other one is completely broken. A failure may occur due to the notch depth not being as desired.

Time vs energy graphs of HDPE specimens is shown in Figure 3.5 and Figure 3.6.

Study in 2017, it was studied impact fracture toughness for HDPE, as a result of this study, when the notch depth ratio of HDPE increases, the absorbed energy per unit area decreases. [16]

When looking at the difference between the specimen with a 1 mm radius in Figure 3.6, it can be seen that the notch depth ratio is higher than the 2nd sample.

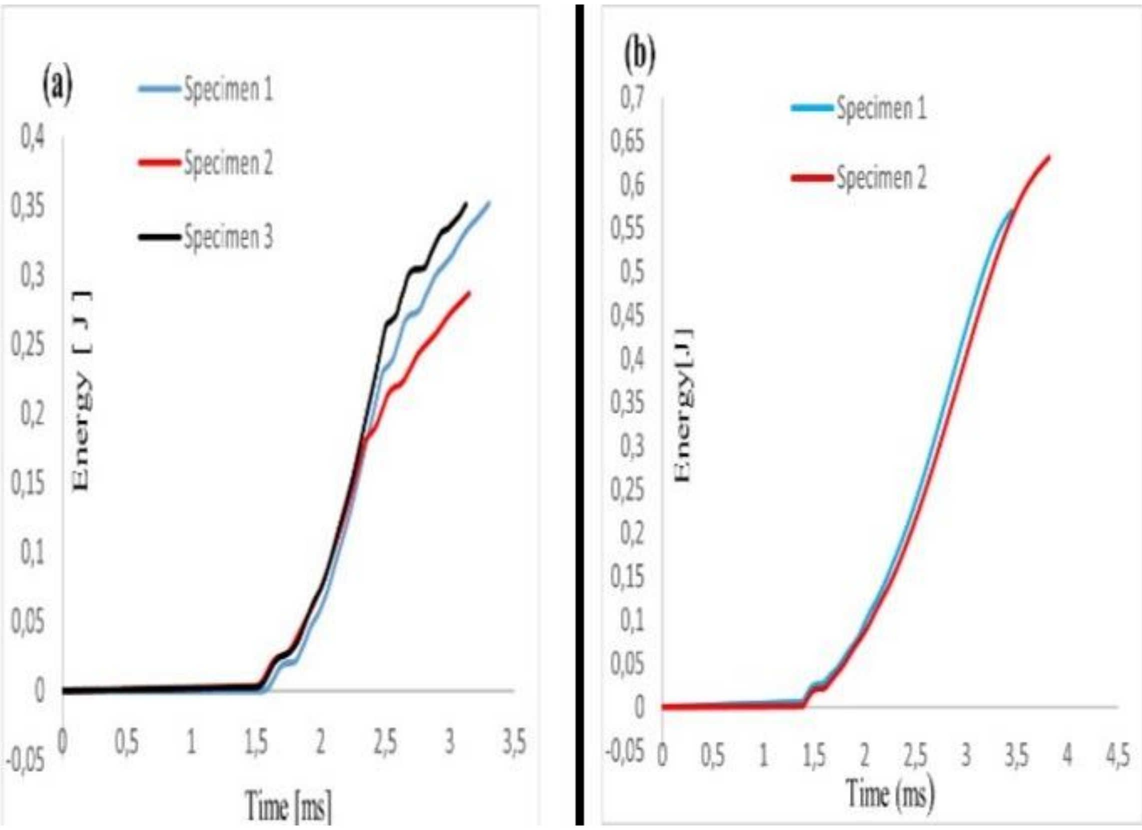

Figure 3. 5 a) Time vs energy of 0,1 mm radii b) Time vs energy of 0,25 mm radii

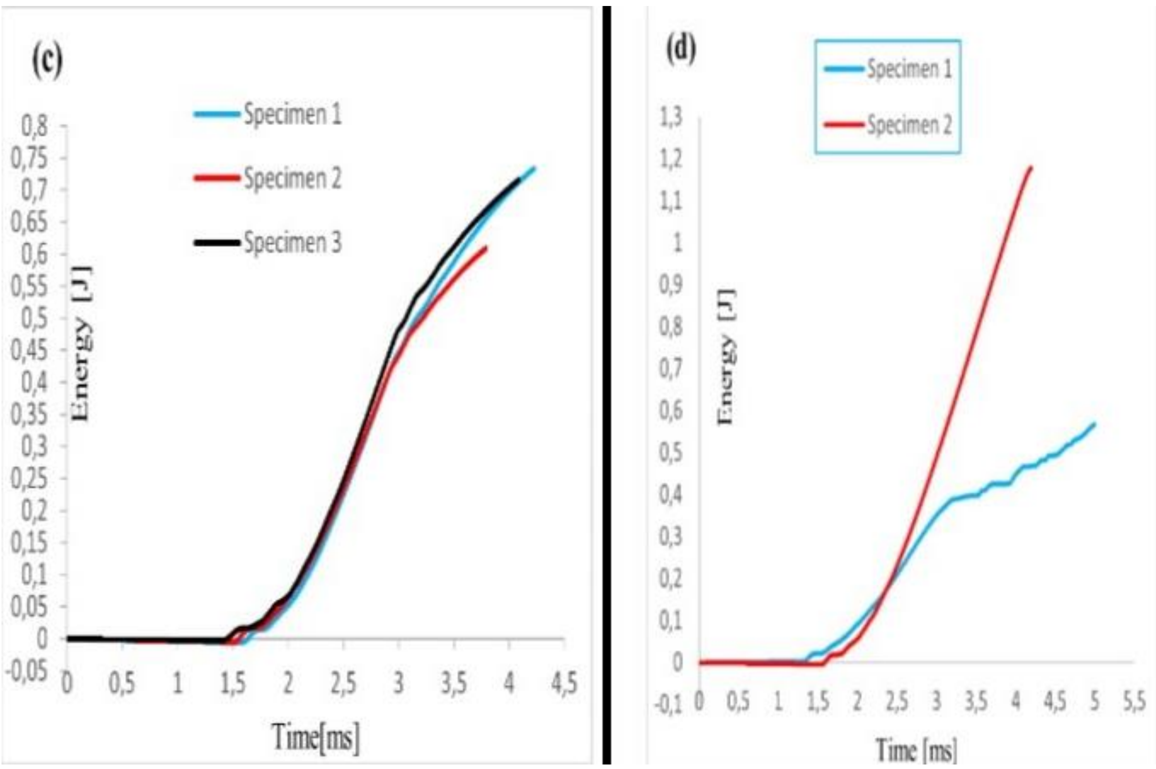

Figure 3. 6 c) Time vs energy of 0,5 mm radii d) time vs energy of 1 mm radii

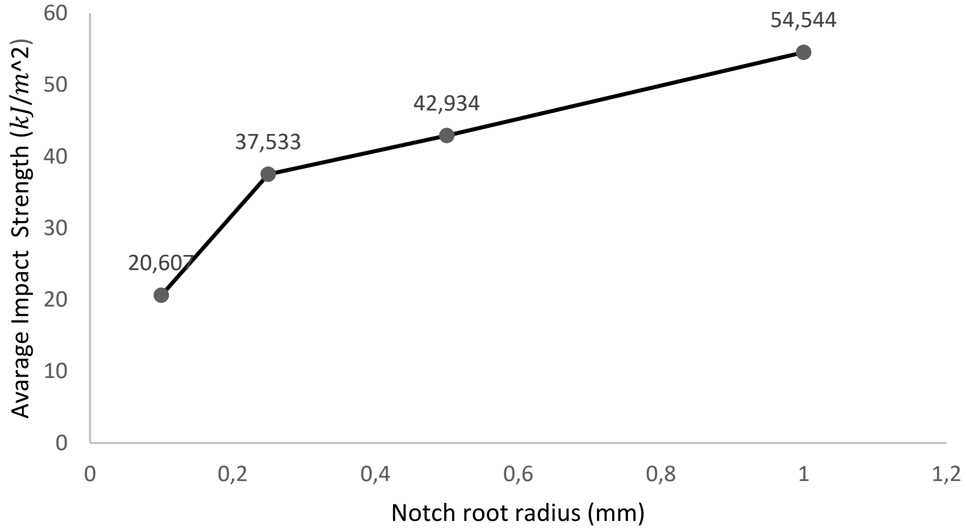

Figure 3. 7 Average impact strengths vs notch root radius graph

4. CONCLUSION

4.1. Conclusion of the Study

This study aimed to design and manufacture with a low cost but close to the notch accuracy rate of the CVN machines used in the market. As a result of the design, a CVN machine suitable for this purpose was decided and the CVN machine was manufactured with the necessary materials. Notch depth test and Charpy impact test were performed with the manufactured the CVN machine.

According to the results of the notch depth test, it is seen that it does not give notch depth in the specified tolerance range. In particular, as the notch depth increases, the distance to the tolerance increases. Some unforeseen design errors occurred in the CVN machine manufactured. One of them is the dimmer integrated to control the speed of the motor. The dimmer allows the speed of the motor to be controlled by changing the current to be transmitted, but the decreasing current also affects the power that the motor can give, for the motor working at low rpm. It has been observed that when notching is performed at low speed, the current to the motor decreases and the motor stops due to the absence of a torque converter. Therefore, notching operations were performed at a higher speed. Since the sheet to which the motor and linear bearing are attached could not provide sufficient rigidity, the motor operating at high speed created more notch depth than desired by making more oscillating movements. As can be seen in the test result, the maximum depth difference occurred in the notches with a radius of 1 mm, where there is more contact with the surface area.

According to the results of HDPE Charpy impact test, it is seen that impact strength of the specimen 20,6 kJ/m^2,37,53 kJ/m^2,42,93 $kJ/m^2$and 54,54 kJ/m^2 respectively with an average. When compared with the samples prepared by cutting HDPE pipes in the literature, close value was reached for the 0,25 mm notch root radius. But the same conditions must be established for a precise comparison to be made. A comparison of the commonly used 0,25 mm notch root radius specimen with the literature was made for the HDPE. In addition, when the absorbed energy is compared with the literature, it is concluded that the notch depth of specimen is greater in this thesis study. As can be seen in the Charpy impact test result, the most difference in energy and impact strength between the samples is at 1 mm radius. It has been observed that when the samples are clamped due to the error in the vise manufacturing, the parts go up when exposed to impact due to the gap in the vise screw. The load at 1 mm radius changed the notch depth of specimens in the vise. For a clear comparison of these sample results, a proven and used CVN machine is needed.

4.2. Recommendation for Further Work

It was observed that the CVN machine manufactured and designed need revision when all the results were evaluated. The knife adapter can be supported by a bearing in order to prevent oscillation movements. A more powerful motor at low revs should be preferred or using the torque converter motor. Elimination of the manufacturing defect in the vise prevents the parts from rising after being impacted. 4 vibration dampers can be used to prevent vibration in the machine and thus the body becomes more rigid. The thickness of the sheet material where the motor and linear bearings are connected to each other should be increased or different materials can be used for the rigidity of the system.

4.3. Evaluation of the Current Work from MÜDEK Perspective

4.3.1. Economic Analysis

This study aimed to make a low-cost CVN machine. Especially a market with more Chinese manufacturers dominates. When many different CVN machines in the market are researched, prices are between 1000 $ and 1500 $ on average. At today’s dollar rate, 1 dollar is 8.67 TL.

The economic analysis of the parts used in this study is shown in Table 4.1.

Table 4. 1 Economic analysis of manufactured CVN machine

Material	**Number of Material**	**Price (TL)**
SBR 16 UU Linear Bearing And Chrome plated bar	2	2*70= 140
Miniature Pillow Blocks	4	4*20 =80
Caliper	1	1*50 TL=50 TL
Electric Motor	1	1*180 Tl= 180 TL
Knife Adapter	1	1*20 Tl = 20 TL
Dimmer	1	1*60 = 60 TL
Linear Rails and Blocks	1	1*70 = 70 TL
Threaded Rods	2	2*20 = 40 TL
Cutting tool steel	1	1*50 TL = 50 TL
Shaft Holders for Chrome Plated	4	4*20 = 80 TL
Workmanship cost and aluminum sheet	-	300 TL
		Total Price = 1070 TL

4.3.2. Real Life Conditions

The CVN machine allows an easy and fast way to make sample notches, which are mandatory for Charpy impact testing. The designed and manufactured CVN machine is now active working condition. However, some revisions are required in the machine in order to obtain more accurate results. Especially for notches with a larger radius, it can give incorrect results in its current state. The specimen should be correctly placed in the vise and it is necessary to make sure that the vise clamps the parts.

4.3.3. Producibility

It is possible easily to manufacture using existing production capabilities. After the motor and vise revisions of the machine are completed, it can be used in laboratories depending on the depth tests and Charpy impact results. Since all the parts used in the machine are produced and sold today, it is easy and fast to produce.

While designing the CVN machine, the parts that are frequently found in the market were taken into consideration.

4.3.4. Constraints

The studies carried out within the scope of this thesis have economic constraints. Economic constraints were effective, especially in motor selection. The inaccuracy of the caliper for use as an alternative to the scale system is also an economic constraint. Another constraint is the Charpy impact test standard for plastic.

REFERENCES

[1] Tóth, L., Rossmanith, H.-P., & Siewert, T. A. (2002) Historical background and development of the Charpy test. European Structural Integrity Society, 3–19.

[2] Erkendirci, Ö., (2012). Charpy impact behavior of plain weave S-2 glass/HDPE thermoplastic composites. *Journal of Composite Materials*. 46. 2835-2841.

[3] Koester, R., and Barcus, S., "Evaluation of Fabrication Method for Making Notches for Charpy V-Notch Impact Specimens," in *Charpy Impact Test: Factors and Variables*, ed. J. Holt (West Conshohocken, PA: ASTM International, 1990), 83-93.

[4] De Souza, J. M., Yoshimura, H. N., Peres, F. M., & Schön, C. G. (2012) Effect of sample pre-cracking method and notch geometry in plane strain fracture toughness tests as applied to a PMMA resin. *Polymer Testing,* 31(6), 834–840.

[5] Martínez, A. B., León, N., Arencón, D., Rodríguez, J., & Salazar, A. (2013). On the effect of the different notching techniques on the fracture toughness of PETG. *Polymer Testing*, 32(7), 1244-1252.

[6] Sokolov, M., and Nanstad, R., "On Impact Testing of Subsize Charpy V-Notch Type Specimens," in *Effects of Radiation on Materials*: 17th International Symposium, ed. D. Gelles, R. Nanstad, A. Kumar, and E. Little (West Conshohocken, PA: ASTM International, 1996), 384-414

[7] Behnia, S., Daghigh, V. Nikbin, K., & Fereidoon, A.. (2016). Influence of Stacking Sequence and Notch Angle on the Charpy Impact Behavior of Hybrid Composites. *Mechanics of Composite Materials*, 52(4), 489-496

[8] Kurishita, H., Kayano, H., Narui, M., Yamazaki, M., Kano, Y., & Shibahara, I. (1993). Effects of V-Notch Dimensions on Charpy Impact Test Results for Differently Sized Miniature Specimens of Ferritic Steel. *Materials Transactions,* 34, 1042-1052.

[9] Nasreldin, A.M., Ibrahim, O.H., & Ghoneim, M.M. (2003). Effect of specimen size and notch geometry on the impact properties of the nuclear reactor pressure vessel steel A533 B. *Proceedings of the Sixth Arab Conference on the Peaceful Uses of Atomic Energy*, Vol. II Scientific Presentation (Reactors, Materials, Fuel Cycles and Nuclear Safety), (p. 626). Egypt

[10] BS EN ISO 2818:1997- Plastics – Preparation of test specimens by machining (ISO 2818:1997)

[11] ASTM D6110-04, Standard Test Methods for Determining the Charpy Impact

Resistance of Notched Specimens of Plastics, ASTM International, West Conshohocken, PA, 2004

[12] Pilipović, A., Rujnić-Sokele, M., Godec, D., & Šercer, M. (2012). Testing of processing and performance properties of marine degradable material. *Polimeri: časopis za plastiku i gumu,* 33(3-4), 106-111.

[13] Shebani, A., Klash, A., Elhabishi, R., Abdsalam, S., Elbreki, H., & Elhrari, W. (2018). The influence of LDPE content on the mechanical properties of HDPE/LDPE blends. *Res Dev Mater Sci,* 7(5), 791-797.

[14] Taşdemır, M., & Gülsoy, H. Ö. (2008). Mechanical properties of polymers filled with iron powder. *International Journal of Polymeric Materials,* 57(3), 258-265.

[15] Alfitouri, A. O., Savaş, M. A., & Evcil, A. (2018). Charpy Impact and Tension Tests of Two Pipeline Materials at Room and Cryogenic Temperatures. International *Journal of Applied Engineering Research*, 13(17), 13321-13334.

[16] Cherief, M.N.D., Elmeguenni, M. & Benguediab, M. (2017), Impact fracture toughness evaluation for high-density polyethylene materials. *J Appl Mech Tech Phy* 58, 335–341

[17] https://polymerdatabase.com/Commercial%20Polymers/HDPE.html) (03/07/2021)

[18] https://www.firat.com/en-us/indoor-piping-system/cold-hot-water-pipe-systems/pprc-product-range/pprc-pipe/technical-specifications-(03/07/2021)

[19] Beltrán, M.A. & González, J.L. & Rivas, Dannah & Hernández, F. & Dorantes, H.. (2017). On the role of microstructural properties on mechanical behavior of API-X46 steel. *Procedia Structural Integrity*. 3. 57-67.