IZMIR KATIP CELEBI UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

NEW GRADE OF THERMOPLASTIC POLYURETHANE WITH HIGH THERMAL CONDUCTIVITY AND LOW COEFFICIENT OF FRICTION

M.Sc. THESIS

Seçkin SEMİZ

Department of Material Science and Engineering

Thesis Advisor: Assoc. Prof. M. Özgür SEYDİBEYOĞLU

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<u>İZMİR KATİP ÇELEBİ ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ</u>

YÜKSEK ISIL İLETİMLİ, DÜŞÜK SÜRTÜNME KATSAYILI YENİ NESİL TERMOPLASTİK POLİÜRETAN

YÜKSEK LİSANS TEZİ

Seçkin SEMİZ

Y130111038

Malzeme Bilimi ve Mühendisliği Anabilim Dalı

Tez Danışmanı: Doç. Dr. M. Özgür SEYDİBEYOĞLU

NİSAN 2017

Seçkin SEMİZ, a **M.Sc.** student of **İzmir Katip Çelebi University** student ID Y130111038, successfully defended the **thesis** entitled "**New Grade of Thermoplastic Polyurethane with High Thermal Conductivity and Low Coefficient of Friction**", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my family,

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28 April 2017 Seçkin SEMİZ

Table of Contents

List of Tables

Page

List of Figures

Abbreviations

TPU	Thermoplastic Polyurethane
FTIR	Fourier Transform Infrared Spectroscopy
SEM	Scanning Electron Microscopy
MPa	Mega Pascal
BN	Boron Nitride
CS	Compression Set

List of Symbols

σ_{max} Maximum Strength

E Young's Modulus

NEW GRADE OF THERMOPLASTIC POLYURETHANE WITH HIGH THERMAL CONDUCTIVITY AND LOW COEFFICIENT OF FRICTION

SUMMARY

Today, thermoplastic polyurethane materials are widely used in many different applications. There are many types of thermoplastic polyurethanes which offers different mechanical and chemical properties according to application area. In addition to the existing properties, thermoplastic polyurethane materials mixed with various additives to obtain specific, targeted thermoplastic polyurethane materials in order to impart different properties to the material for application.

In this study, materials of the sealing elements are approached which is one of the most important parts of the hydraulic & pneumatic systems widely used in industry. Nowadays when energy efficiency and product life become vital, it is quite important that prolongation of the sealing element life, increasing the energy efficiency and reducing maintenance requirements for hydraulic & pneumatic sealing elements sector. This study gains importance in terms of bringing the properties such as low coefficient of friction and high thermal conductivity coefficient in materials of hydraulic pneumatic sealing materials without breaking the standard physical and chemical properties of the material.

Standard features expected from hydraulic & pneumatic sealing materials summarized as tensile strength, elongation at break, hardness, deformation under pressure (compression set) and wear resistance. In addition to these properties of standard materials, it envisaged that imparting low coefficient of friction to materials will reduce wearing because of friction and heat formation, imparting high thermal conductivity will facilitate transferring the heat generated from the material to the surrounding area. If these two properties are insufficient, burn spots and abrasions due to temperature increase observed in the working surfaces of the sealing elements. Herewith these problems cause leakage that is the indication of failure. By preventing these situations, the sealing elements will be able to benefit from the sector with higher energy efficiency and longer working life.

Four different additive materials such as boron nitride, MoS_2 ,graphite and PTFE were used at three different doses each to gain the specified properties to the thermoplastic material which is used in this study. The base material compounded with the additives was re-granulated with twin-screw extruder and after heat treatment of the materials, test plaques and sealing elements were produced with the help of plastic injection machines.

FTIR, thermal conductivity coefficient, tensile, compression set, coefficient of friction and friction tests carried out to examine the properties expected to change.

When all the results analyzed according to the tests performed, it has been observing that Sample 6 which has 5% PTFE acquired the targeted properties without deteriorating the existing properties. In this compounded material, the coefficient of thermal conductivity increases and the coefficient of friction decreases while the hardness, stress at 100% strain and compression set values are within acceptable limits.

YÜKSEK ISIL İLETİMLİ, DÜŞÜK SÜRTÜNME KATSAYILI YENİ NESİL TERMOPLASTİK POLİÜRETAN

ÖZET

Termoplastik poliüretan malzemeler günümüzde endüstrinin birçok farklı yerinde yaygın olarak kullanılmaktadır. Uygulama alanına göre farklı mekanik ve kimyasal özellikler gösteren termoplastik poliüretanların birçok çeşidi vardır. Mevcut özelliklerin yanında, uygulamaya yönelik olarak malzemeye farklı özellikler kazandırabilmek için termoplastik poliüretan malzemeler çeşitli katkı maddeleriyle karıştırılarak spesifik, hedefe yönelik termoplastik poliüretan malzemeler elde edilmektedir.

Bu çalışmada, endüstride yaygın olarak kullanılan hidrolik ve pnömatik sistemlerin en önemli parçalarından biri olan sızdırmazlık elemanları malzemeleri ele alınmıştır. Enerji verimliliğinin ve ürün ömürlerinin önemli hale geldiği günümüzde hidrolik ve pnömatik sızdırmazlık elemanları ömürlerinin uzatılması, enerji verimliliklerinin arttırılması ve bakım gereksinimlerinin azaltılması hidrolik pnömatik sızdırmazlık elemanları sektörü için büyük önem taşımaktadır. Bu çalışma, hidrolik pnömatik sızdırmazlık elemanları malzemelerinde düşük sürtünme katsayısı ve yüksek ısıl iletim katsayısı gibi özelliklerin malzemenin standart fiziksel ve kimyasal özelliklerini bozmadan malzemeye kazandırılması açısından önem kazanmaktadır.

Hidrolik & Pnömatik sızdırmazlık elemanları malzemelerinden beklenen standart özellikler; çekme dayanımı, kopma uzaması, sertlik, baskı altında deformasyon ve aşınma dayanımı olarak özetlenebilir. Standart malzemelerin sahip oldukları bu özelliklerin yanında, malzemelere düşük sürtünme katsayısının kazandırılmasının, malzemenin sürtünmeden kaynaklı aşınmasını ve ısı oluşumunu azaltacağını, yüksek ısıl iletim katsayısının kazandırılmasının da oluşan sıcaklığın malzemeden çevreye transferinin kolaylaştıracağı öngörülmüştür. Bu iki özelliğin yetersiz olduğu durumlarda sızdırmazlık elemanları çalışma yüzeylerinde sıcaklık artışı sebebiyle yanmalar ve aşınmalar gözlemlenmektedir. Sonuç olarak da bu problemler sızdırmazlık elemanı için başarısızlık göstergesi olan sızıntıya sebep olur. Bu durumların önlenmesi sayesinde sızdırmazlık elemanları daha yüksek enerji verimliliği ve daha uzun çalışma ömürleriyle sektörde avantaj elde edebilecektir.

Çalışmada kullanılan termoplastik poliüretan malzemeye belirtilen özelliklerin kazandırılabilmesi için boron nitrür, MoS_2, PTFE ve grafit gibi dört farklı katkı malzemesi üçer farklı dozajda kullanılmış ve termoplastik poliüretan malzeme ile çekilerek toplamda on iki farklı çeşit oluşturulmuştur. Katışkıları yapılan malzemeler çift vidalı ekstruder ile çekilmiş ve ısıl işlemleri yapıldıktan sonra plastik enjeksiyon makinası ile sızdırmazlık elemanı ve test plakaları üretilmiştir.

Değişmesi beklenen özelliklerin incelenebilmesi için FTIR, ısıl iletim katsayısı, çekme kopma, sıkıştırma, sürtünme katsayısı ve özel test tertibatıyla sürtünme karşılaştırma testleri yapılmıştır.

Yürütülen testlere göre tüm sonuçlar incelendiğinde %5 PTFE ile oluşturulmuş altı numaralı malzemenin mevcut özellikler bozulmadan hedef özellikleri malzemeye kazandırdığı gözlemlenmiştir. Bu malzemede sertlik, %100 uzama altındaki gerilme ve baskı altında deformasyon değerleri kabul edilebilir sınırlar içinde kalırken, ısıl iletim katsayısı değeri artmış ve sürtünme katsayısı değeri azalmıştır.

1. INTRODUCTION

1.1 Background

Usage of thermoplastic polyurethane materials in hydraulic and pneumatic sealing systems is increasing day by day. The biggest manufacturers of thermoplastic materials in the world are working on developing new properties to existing materials according to customer requirements.

Accompany with industrial developments, efficiency of energy is an increasing trend all around the world. Energy efficiency is a blooming trend regarding industrial developments of companies around the world. On the other hand, increasing efficiency of sealing system studied in hydraulic and pneumatic sector like in every segment of industry. The first step of this increase of efficiency is using the right material for each application. On the other hand, the selected material must provide several necessities like minimum leakage, performing silently, maximum life cycle and shelf life, avoiding get warm due to friction and minimum friction coefficient. In this study, it is aimed to improve sealing properties and extend life cycle of thermoplastic polyurethane.

1.2 Definition of hydraulic and pneumatic

There are three methods in industry for power transfer from one to another point. Firstly, mechanic power transfer is possible with usage of shafts, chains, belts and gears. Secondly, electrical power transfer is only possible with the existence of wires, transformers and other various elements. In addition, the third method is fluid power transfer which solely through fluid or gas in an imprisoned space.

Fluid power technology transfers and controls the forces through mechanical systems and elements where environmental conditions restricted with the help of pressurized fluids. Gases and fluids considered as well fluids. Fluid power systems combine both hydraulic (stands for water in Greek) and pneumatic (stands for air in Greek) systems. Hydraulic systems used widely in industry for huge forces needed for the comparison with pneumatic systems. If you compare the first setup costs, hydraulic systems are more expensive than pneumatic systems. The first reason of this expensiveness is pressure. In hydraulic systems, the media has to be incompressible fluid as water and oil. For this reason, the pressure of the system theoretically can increase unlimitedly. The media that used in pneumatic systems is air that we breathe. Air compressors pressurize the air up to 10 - 12 bar. Pressurizing the air more than 10 bar is energy loss because of compressibility of air. That is why pneumatic systems are limited with 10 - 12 bar.

1.2.1 History of fluid power

Fluid power technology was invented in 1650 with the discovery of Pascal's law. According to Pascal (1650), "in a fluid at rest in a closed container, a pressure change in one part is transmitted without loss to every portion of the fluid and to the walls of the container". With this law, Pascal laid the foundations for the next development of hydraulics with the hydrostatic law. Joseph Bramah considered as a founder of hydraulics technology. In the lights of this information, hydraulic systems started to be a part of industry.

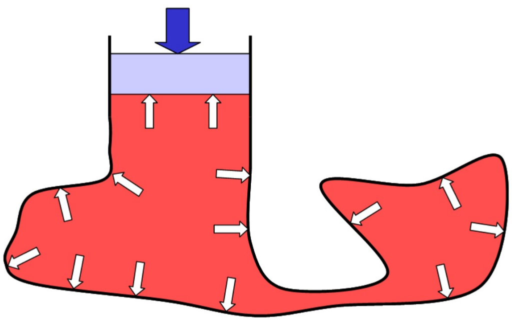


Figure 1.1: Pascal's law.

1.2.2 Usage of hydraulic and pneumatic systems

Hydraulics and pneumatics are widely used in industry to produce of services and goods that almost covered by all sectors. A portion of the business fields are reliant on the capacities that liquid power manages. Some of the fluid power applications illustrated on Table 1.1.

Table 1.1: Some applications of fluid power [3].

Farming	Ploughs, water and chemical sprayers, harvesters etc.
Automobiles	Steering systems, brake systems, suspension systems, hydrostatic transmission systems etc.
Construction industry/equipment	Excavators, lifts, bucket loaders, crawlers, post-hole diggers, road graders, road cleaners, road maintenance vehicles, tippers etc.
Defense	Missile-launching systems, navigation controls etc.
Fabrication industry	Hand tools such as pneumatic drills, grinders, borers, riveting machines etc.
Food and beverage	All types of food processing equipment, wrapping, bottling etc.
Foundry	Full and semi-automatic molding machines, tilting of furnaces, die-casting machines etc.
Glass industry	Vacuum suction cups for handling etc.
Instrumentation	Used to create/operate complex instruments in space rockets, gas turbines, nuclear power plants, industrial labs etc.
Jigs and fixtures	Work holding devices, clamps, stoppers, indexers etc.
Machine tools	Automated machine tools, numerically controlled (NC) machine tools etc.
Materials handling	Jacks, hoists, cranes, forklifts, conveyor systems etc.
Medical	Medical equipment such as breathing assistors, heart assist devices, cardiac compression machines etc.
Movies	Special-effect equipment etc.
Mining	Rock drills, excavating equipment, ore conveyors, loaders etc.
Newspapers and periodicals	Edge trimming, stapling, pressing, bundle wrapping etc.
Oil industry	Off-shore oil rigs etc.
Plastic industry	Automatic injection molding machines, raw material feeding, jaw closing, movement of slides of blow molder etc.

1.2.3 Components of hydraulic and pneumatic systems

Fluid power systems are power transferring units employing pressurized fluids for transmitting energy from an energy generating source to an energy using point to accomplish useful work. Figure 1.2 and Figure 1.3 shows sample hydraulic and pneumatic systems with their basic components.

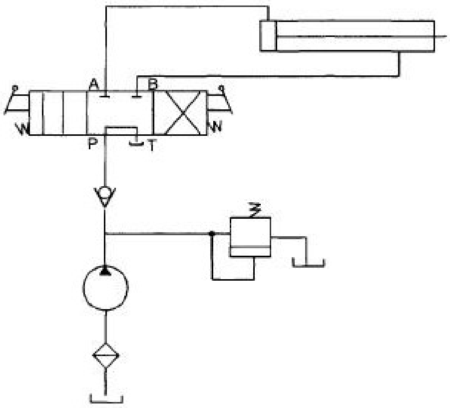


Figure 1.2: Basic hydraulic system with components [2].

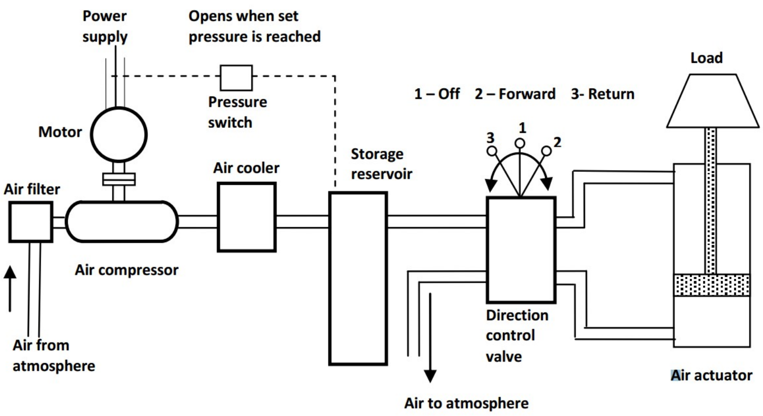


Figure 1.3: Basic pneumatic system with components [3].

1.2.3.1 Hydraulic and pneumatic cylinders

Fluid powered cylinders convert fluid pressure created by compressors or pumps to a linear or rotary mechanical movement. When fluid pressure acts on the piston, the pressure transmitted to the piston rod, resulting in linear motion. The piston rod thrust force created by the fluid pressure acting on the piston is easily determined by multiplying the line pressure by the piston area. In general, cylinders are linear actuators that can force and draw a heap however, when it mounted on a revolving joint straight move makes as a turning movement. The principle of operation is basically explainable with Pascal’s law. There are couple different types of cylinders depending on application of system. Single acting cylinders have a one-way movement creation. Instroke motion of the load occurs with gravity or a loaded spring. The second type of cylinders are double acting ones. This type of cylinders which are most common, has two connection ports for media in and out. One of the port is for outstroke motion and the second one is for instroke motion. This type of cylinders transforms the fluid power to linear motion for forward and backward direction. Figure 1.4 shows components of typical double acting hydraulic cylinder.

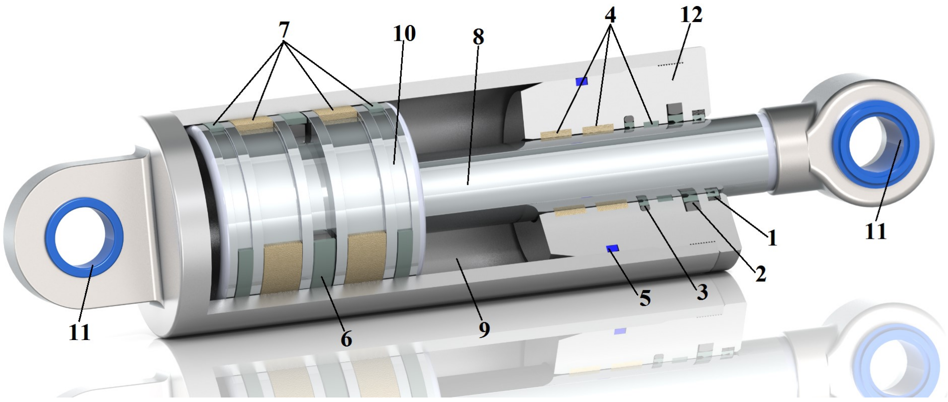


Figure 1.4: Basic cylinder design with numbered parts.

The cylinder located above, has the parts detailed below;

1: Wiper seal

2: Rod seal

3: Rod buffer seal

4: Rod guiding rings

5: Static seal

6: Piston seal

7: Piston guiding rings

8: Rod

9: Bore / Barel

10: Piston

11: Cylinder joints

12: Head

Basically, hydraulic and pneumatic cylinders occur from the same parts. When the operating pressures considered, some differences needed in designs. First of it is bore material and thickness. In pneumatic applications bore material is usually aluminum and thickness is couple millimeters on the grounds that operation pressure limited to 10 bar. In the hydraulic applications, bore and the rod materials are usually hardened steel.

Calculation of pressure–force transformation is force equals pressure cross area. There is a point that must be considered. The area used for pushing force is smaller than the other side. This means pushing and pulling forces are different as shown below.

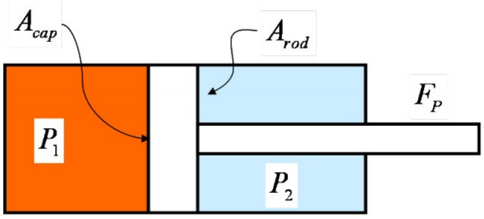


Figure 1.5: Forces of a cylinder.

The area shown as A_{cap} is bigger than the area shown as A_{rod}. That is the reason why the force F_1 is bigger than force F_2 under the same pressure value.

1.2.3.2 Pumps, motors and compressors

In hydraulic systems, duty of pressurizing the media is performed by a hydraulic pump driven by electric motor or combustion engine. Driving a pump is usually performed by an electric motor. Combustion engines are used in mobile hydraulic systems or precaution situations like moments when electricity can be cut off. The most common hydraulic pumps are gear, vane and radial piston pumps. If the media is air which means pneumatic system, duty of pressurizing the media is performed by air compressors. Ideal hydraulic pump and motor are defined by the relations between fluid pressure P, flow Q, shaft torque T and velocity w. In pneumatic applications choosing the compressor is determined according to pressured air flow needed. Consequently, pumps are source of pressurized liquid media for hydraulic systems, compressors are source of pressurized air for pneumatic systems.

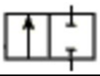
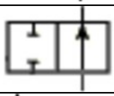
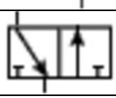
If the motion needed is rotary, motors can be used as actuator in hydraulic and pneumatic systems. Motors are powered by pressurized media and transforms fluid power to mechanical power. A basic hydraulic gear pump is shown in Figure 1.6.

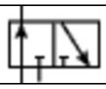
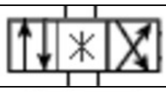
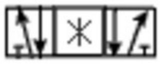
Figure 1.6: Hydraulic gear pump.

1.2.3.3 Control valves and valve symbols

Valves are important parts of the fluid power systems and they appear in all fluid power system. Valves are categorized by purpose, which includes directional control valves for transferring fluid flow to one of the cylinder or hydro motor port, pressure control valves for regulating the fluid pressure at a constant value and flow control valves for curbing the flow value in a line which determines the velocity of the cylinder. Valves are named by the number of ports and operating positions. For example, a 5 way and 3 position valves are commonly found in pneumatic systems one port for supplying the pressured air, one port for exhaust of the system and three ports for positioning the cylinder. In the first position, which is middle valve doesn't let the air flew. Valve must be triggered to change the spool position. This trigger can be an electrical spark. When the spool changed position, air starts to fill a port of the cylinder. At the same time other port of the cylinder is connected to exhaust line to make the pressure equal with atmosphere. For changing the motion direction, other coil of the valve is triggered and connections are reversed. Table 1.2 shows hydraulic and pneumatic valve symbols.

Table 1.2: Hydraulic and pneumatic directional control valve symbols.

Valve Detail	**Symbol**
	Normally closed valve with 2 ports and 2 positions.
	Normally open valve with 2 ports and 2 positions.
	Normally closed valve with 3 ports and 2 positions.

	Normally open valve with 3 ports and 2 positions.
	Valve with 4 ports and 2 positions.
	Valve with 4 ports and 3 positions (center position can have various flow paths)
	Valve with 5 ports and 2 positions
	Valve with 5 ports and 3 positions

Actuation types of the valves are shown in Figure 1.7. In the figure, type a symbols push button, type b symbols lever, type c symbols spring return, type d symbols solenoid and type e symbols pilot line actuating valve.

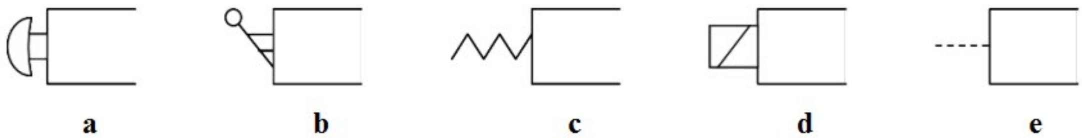


Figure 1.7: Actuation types of the valves.

1.2.3.4 Accumulators

Accumulators are commonly used and important parts of hydraulics systems for temporary storing pressurized oil in system. Accumulators supplies temporary peak fluid power, when flow rate is insufficient. If the system aims a pure and smooth motion, accumulators take a position as shock absorber. These important components of the hydraulic systems connected to pressure line directly. In case of pressure decreasing, accumulators feeds the system and keeps the pressure constant. Accumulators are equivalent to capacitors in an electrical system and to a spring in mechanical system. The most common accumulators are bladder type accumulators. They pre-charged with nitrogen gas according to operating pressure. Selection of accumulator type and volume made according to fluid’s pressure and flow rate needed. Cross section of a bladder type accumulator is shown in Figure 1.8.

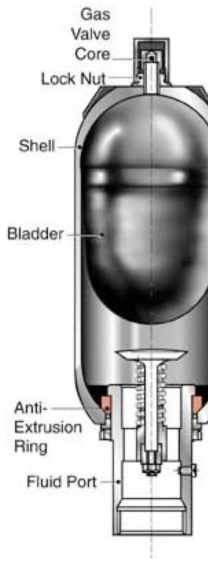


Figure 1.8: Bladder type accumulator [4].

1.2.3.5 Filters

During the operation of the hydraulic system, media picks up contaminating particles from outside of the cylinder. There are kinds of hydraulic cylinders that work in dirty environments or places too much dusty. In consequence of wearing of the wiper, foreign matters like dust or dirt contaminates the media. These dirt particles are tiny grit that cause additional abrasive wearing. Clumps of particles can clog tiny clearances in precision valves and cylinders that can lead to also corrosion [1]. In every type of hydraulic systems, components need filters in the hydraulic circuit. Figure 1.9 shows hydraulic filters in circuit. The filter numbered 1 is pressure filter. It allows eliminating particles from pressured oil. The filter numbered 2 is return line filter. It allows eliminating particles form non-pressured oil at the end of the hydraulic circle.

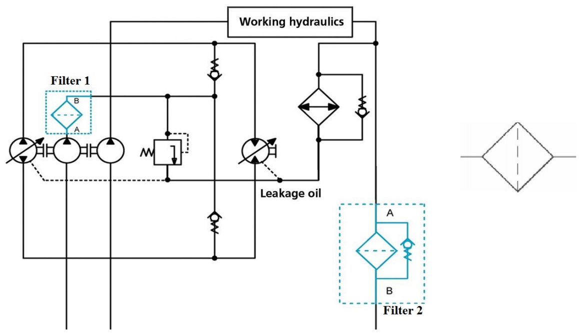


Figure 1.9: Filters in hydraulic diagram and ISO symbol.

The aim of pressure filter is protecting the valves and cylinders from particles. However, if the hydraulic oil contaminated in valves of cylinders, return line filter eliminates the dirt from oil. Therefore, the media of hydraulic system is always keeps the purity. Choosing of the right filter element done according to fluid flow, maximum pressure of the system and the dirt's particle size that will be allowed.

In the pneumatic systems, there is one filter needed. At the beginning of the air connection of every pneumatic system, air filter, regulator and lubricator should be included. An air filter cleans compressed air. It traps solid particles (dust, dirt and rust) and separates liquids (water and oil) entrained in the compressed air. Duty of regulators is setting the operating pressure of the system. The combination of filter, regulator and lubricator is called as FRL. A basic FRL is shown in Figure 1.10 below.

Figure 1.10: Pneumatic FRL (Filter, Regulator and Lubricator) [5].

1.2.3.6 Reservoirs

The main aim of reservoirs in hydraulic systems is providing hydraulic fluid at room temperature in atmospheric pressure. Basically, a reservoir is oil storage tank connected to the atmosphere through a breather. Reservoirs have hydraulic components like pumps and motors valves and lines on it. The fluid returned to tank is always hotter than the fluid in reservoir. To avoid warming the fluid in reservoir, heat exchangers used to cool the fluid. Heat exchangers work according to reservoir temperature. If the temperature of reservoir exceeds the limit temperature for system (usually limit is 50 ºC for hydraulic systems) heat exchange cools the fluid. Therefore, reservoir temperature is always limited to preset temperature value. A hydraulic reservoir needs cleaning periodically. For reaching to inner surface of the reservoir there must be a detachable cap which is called man hole. Figure 1.11 shows an ordinary hydraulic reservoir.

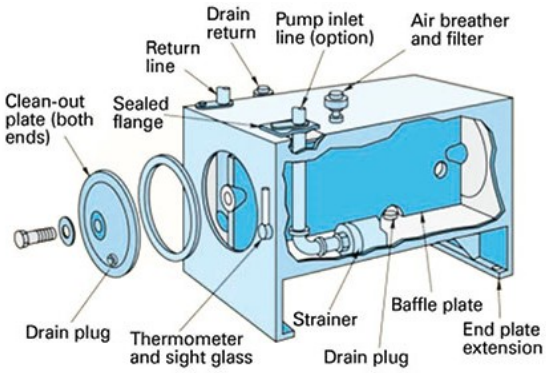


Figure 1.11: Hydraulic reservoir [6].

1.2.3.7 Hoses and fittings

Transmitting the pressurized media among various components is done with hoses and fittings. Hoses used in hydraulic systems have couple layers according to system pressure. In the innermost layer is a hose that transmits the fluid. The outer layer of it is reinforcement fibers. The outmost layer of the hose is cover. Number and material of layers can be change according to system pressure. Hose type is chosen according to fluid pressure and flow rate. Figure 1.12 shows the layers of a basic hose.

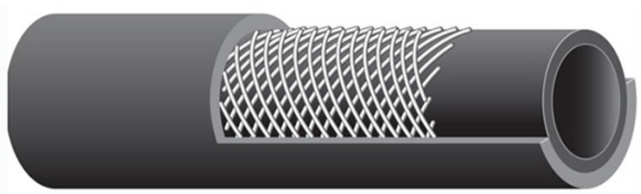


Figure 1.12: Layers of hydraulic hose.

For connecting the hydraulic hoses to a port, fittings must be used. Diameter of the fittings are choosen according to flow rate. Fittings are pressed to hoses by hydraulic press according to customer's special requirements. A standard hydraulic hose is shown in Figure 1.12.

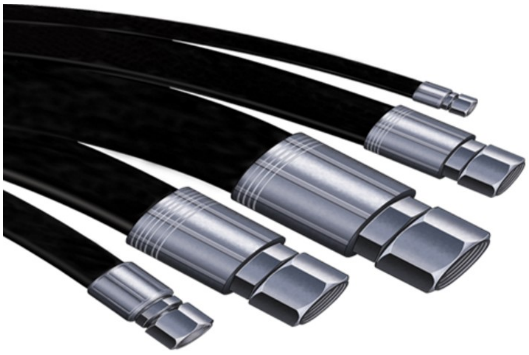


Figure 1.13: Fittings pressed hydraulic hose.

In pneumatic systems, pressure is limited to 10 – 12 bar because of the compressibility of the air. Due to standard air pressure, pneumatic hoses are standard. The only variable thing is hose diameter. Usually pneumatic hoses made from thermoplastic polyurethane. To connecting the pneumatic hoses there are different types of fittings as shown in Figure 1.14.

Figure 1.14: Fittings widely used in pneumatic systems.

1.2.3.8 Gauges and accessories

Gauges are widely used in hydraulic and pneumatic systems to observe operating pressure. Gauges are important parts of hydraulic and pneumatic systems to control the pressure in case of over loading. Figure 1.15 shows hydraulic and pneumatic gauges.

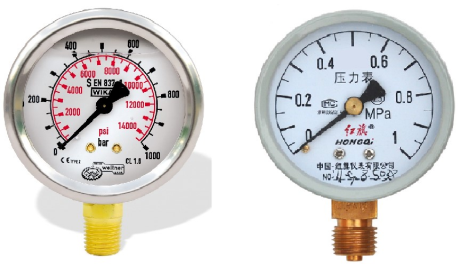


Figure 1.15: Hydraulic and pneumatic pressure gauges.

Observing the system pressure in different points on hydraulic systems, makes the system safer.

1.2.4 Hydraulic circuit analyses

Figure 1.16 shows a basic hydraulic circuit. This hydraulic system incorporates a hydraulic pump, a 4 way, 3 position, center off valve and double acting hydraulic cylinder. The pressure relief valve that limits the maximum pressure of the hydraulic system takes place between the pump and return line. Operator can control the system pressure on pressure gauge. If a failure occurs, operators can interfere to the system. Directional control valve has 4 ports and 3 final positions. As shown in valve figure, at the two opposite sides of the valve, it has two solenoid control devices that allow changing the valve positions. At the middle position of valve, all the ports are off which means hydraulic cylinder locked under pressure. Unless the solenoid triggered with an electrical spark, cylinder cannot change the position. In these types of applications, cylinder can act and wait at the specific position. If one solenoid is triggered, cylinder moves to a direction. If another solenoid is triggered, cylinder moves to another direction. Hydraulic elevators use this design to wait at the target floor. Valve has four ports, which are; pressure line, tank line, cylinder forward pressure line and cylinder backward pressure line. Tank line is used for transferring the oil at the end of the circuit.

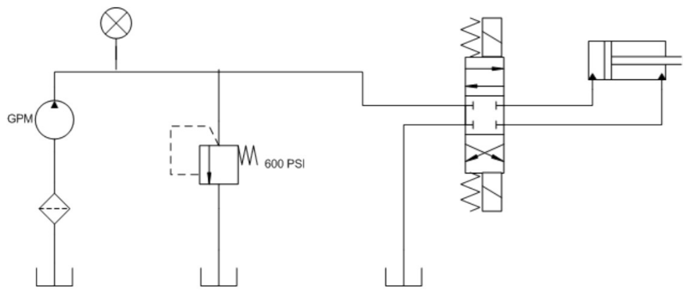


Figure 1.16: Example of basic hydraulic circuit.

1.2.5 Pneumatic circuit analyses

Figure 1.17 shows a basic pneumatic circuit. This pneumatic system includes a FRL (Filter, Regulator and Lubricator), 5 way, 2 position directional control valve and pneumatic cylinder. Compressor supplies the air for system. At the beginning of the pneumatic circuits, first pneumatic component is always FRL. This component firstly filters the air from dust, oil and particles. After filtering the air regulator sets the operating pressure. Operating pressure is set according to needed force. Regulated air is lubricated in lubricator. After this point, pressurized air is appropriate for using in pneumatic system. Directional control valve is normally supplies air to cylinder's backward port (Port B). In this position of valve, port A is connected to atmosphere to relief the pressure. Valve is controlled by mechanical button to change the position. If you push the button on valve, valve changes the positon and cylinder moves forward (outstroke). When the mechanical button is relieved, cylinder moves backward (instroke). In these types of valves which have no middle position, cylinder cannot wait at the position between minimum and maximum stroke points.

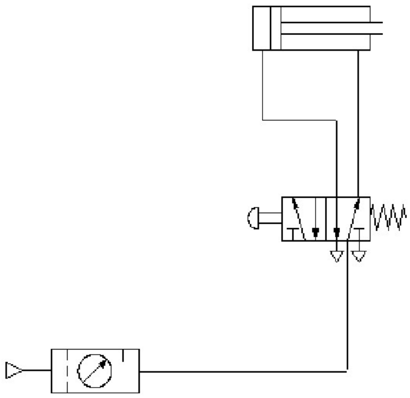


Figure 1.17: Example of basic pneumatic circuit.

1.2.6 Differences between hydraulic and pneumatic systems

Fluid power devided into two areas. Hydraulics and pneumatics differ in several ways, but the most notable fact is each system uses a different media. Both systems have their own distinct advantages and ideal applications such as heavy lifting and operating costs. The main differences are detailed in Table 1.3 below;

Table 1.3: Hydraulic and pneumatic differences.

Hydraulic Systems	Pneumatic Systems
Uses a relatively incompressible liquid	Uses compressible air
Slow, smooth motion	Quick, jumpy motion
Very precise	Not as precise as hydraulics
Self-lubricating	Lubricant must be added

Not as clean (some leakage exist)	Generally cleaner
Pressures of 30 to theoretically unlimited	Pressures of around 8 bar
Complicated installation	Easy installation
Limited energy storage	High energy storage
Medium noise	High noise
High peak power	Medium peak power
High operating cost	Medium operating cost
High maintenance cost	Low maintenance cost

As detailed above, pneumatic systems are cheap for setup costs but if the system needs high forces and smooth motions, hydraulic systems are always preffered. Both systems are suitable for automation control easily under favour of PLC and software.

1.2.7 Sealing element types of hydraulic and pneumatic systems

Hydraulic and pneumatic seals are mechanical devices placed under compression between two metal objects, to prevent the escape of fluids or gases. Seals are named according to part of the cylinder that will be sealed.

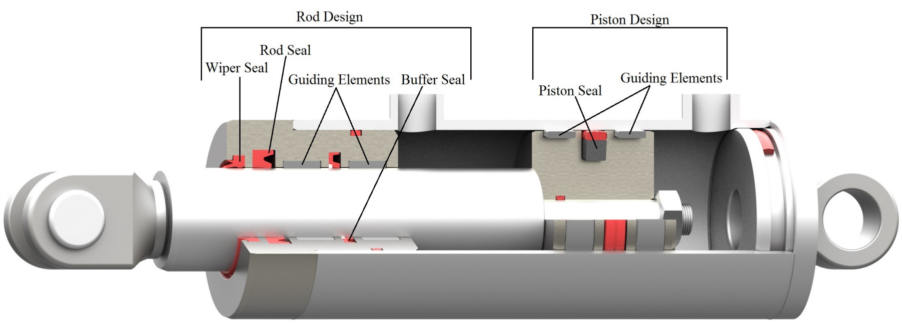


Figure 1.18: Seals in a typical hydraulic cylinder.

Piston seal acts as pressure barrier and prevents fluid passing the piston. This seal type is important for controlling the cylinder motion and position. Rod seal acts as pressure barrier and keeps operating fluid inside the cylinder. Rod seal is important for preventing the leakage to the out of the cylinder and also it regulates the fluid film which extends the life cycle of the surfaces. This fluid film inhibits the rod from corrosion and lubricates all parts of the rod design that includes guide elements, rod seal, buffer seal and wiper seal. Buffer seal protects the rod seal from sudden fluid pressure peaks. It also keeps the system contaminants such as dirt or metal particles from damaging the rod seal. Wiper seal inhibits entering the contaminants to cylinder and hydraulic system. On the other hand, wiper seal accepts the lubrication film back into the cylinder when the rod retracts. Guide rings locate both of piston and rod designs. They keep the piston and bore or rod and head accurately centered in the cylinder assembly. Guide rings are the most important parts of the cylinders with the duty of centering the cylinder parts. Life time of the seals will be too short because of the wearing in an uncentered cylinder design. There are different rod seal and piston seal geometries as shown in figure 1.19 and figure 1.20.

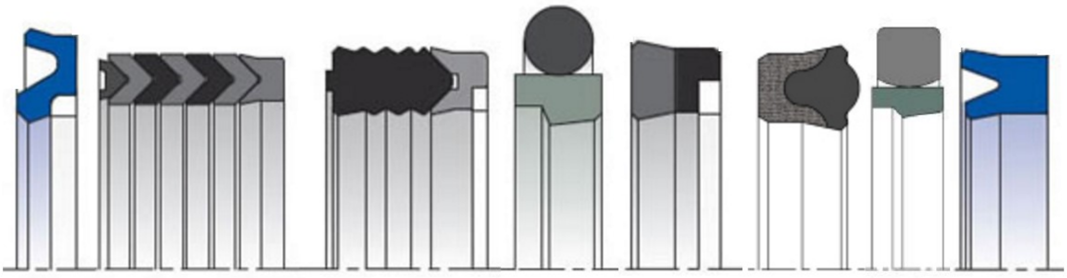


Figure 1.19: Types of rod seals [7].

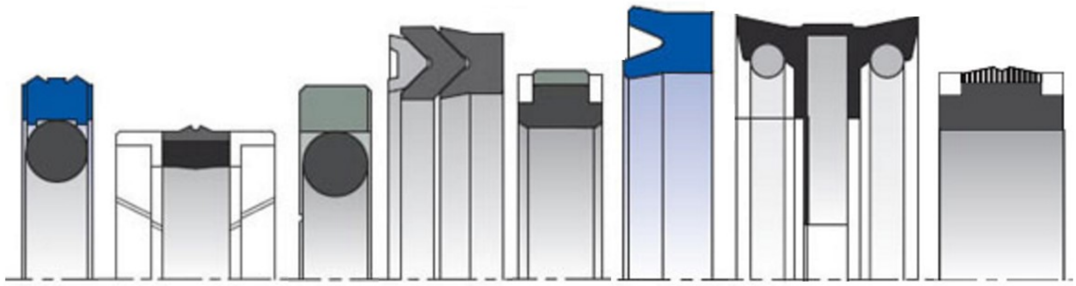


Figure 1.20: Types of piston seal [7].

There are different types of sealing element geometries and materials according to application area, operating temperature, speed and pressure. First step of designing a hydraulic or pneumatic cylinder is specifying the conditions that the cylinder will be operated under. After specifying maximum velocity, operating pressure and maximum environment temperature, seal design can be chosen. Seal designs are detailed according to sectors below;

Agriculture Hydraulic Seal Design Example;

This design includes Kastaş K06 wiper seal, K22 rod seal, K86 guiding element and K85 static seal in rod design, K18 piston seal and K83 static seal in piston design.

Rod Design Piston Design

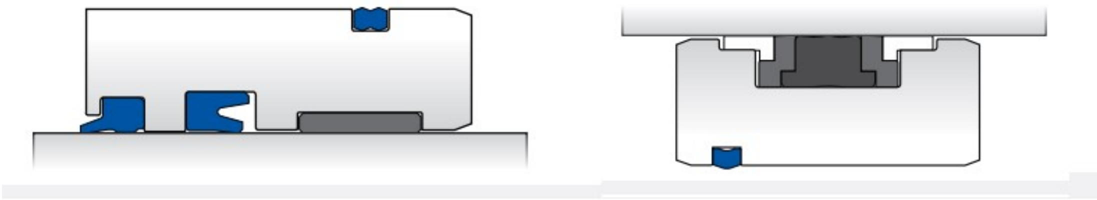


Figure 1.21: Example hydraulic sealing design for agriculture sector [7].

Construction Machinery Seal Design Example;

This design includes Kastaş K05 wiper seal, K33 and K35 rod seal, K75 guiding element and K84 static seal in rod design, K19 piston seal, K75 and KBT guiding elements and K81 static seal in piston design.

Rod Design Piston Design

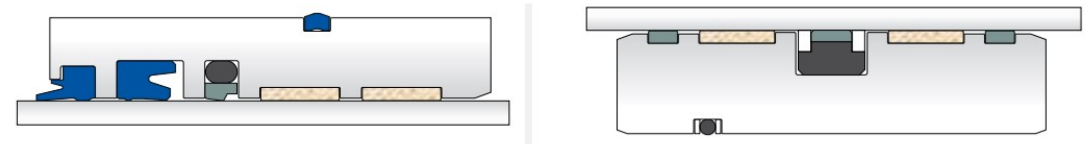


Figure 1.22: Example of hydraulic sealing design for construction sector [7].

Hydraulic Press Seal Design Example;

This design includes Kastaş K11 wiper seal, K22 and K35 rod seal and K73 guiding element in rod design, K17 piston seal, K73 and KBT guiding elements in piston design.

Rod Design Piston Design

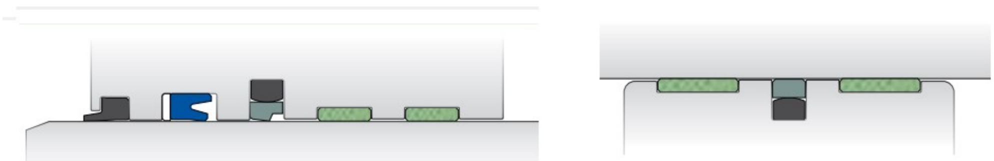


Figure 1.23: Example of hydraulic sealing design for hydraulic press sector [7].

Mobile Hydraulic Seal Design Example;

This design includes Kastaş K12 wiper seal, K22 and K29 rod seal, K73 guiding element and K84 static seal in rod design, K49 piston seal, KBT guiding elements and K83 static seal in piston design.

Rod Design Piston Design

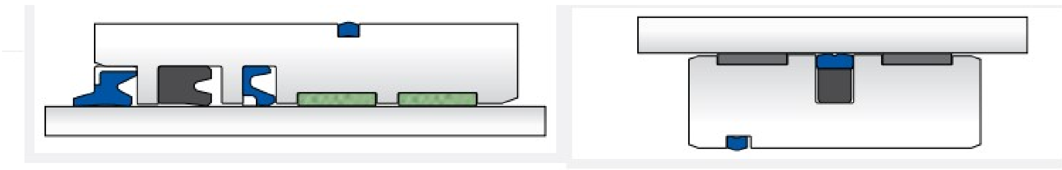


Figure 1.24: Example hydraulic sealing design for mobile hydraulic sector [7].

Metal Processing Seal Design Example;

This design includes Kastaş K06 wiper seal and K01 rod seal in rod design, K03 piston seal in piston design.

Rod Design Piston Design

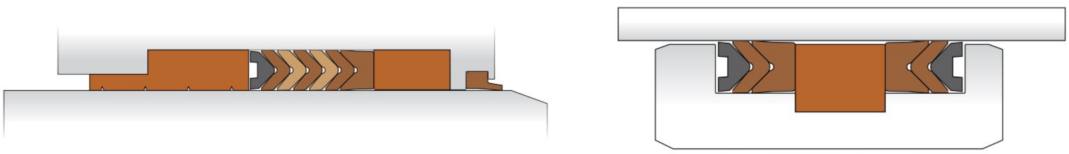


Figure 1.25: Example of hydraulic sealing design for metal processing sector [7].

Plastic Injection Machines Seal Design Example;

This design includes Kastaş K705 wiper seal, K22 and K35 rod seal and K73 guiding element in rod design, K17 piston seal, KBT and K73 guiding elements in piston design.

Rod Design Piston Design

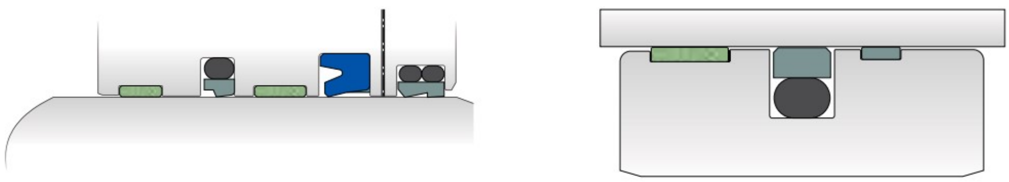


Figure 1.26: Example of hydraulic sealing design for plastic injection sector [7].

1.2.8 General assembly information of sealing elements

There are many problems due to incorrect assembly of hydraulic and pneumatic sealing elements. It is vital that assembly rules should be obeyed in order to make successful applications in hydraulic and pneumatic cylinders.

- It is very important that before assembly of the components, the entire system and the fitting components must be cleaned out.
- The measures of housing and the seal, radius, the chamfer and the surface quality must be checked and cleaned out.
- The burs on sharp edges are very dangerous.
- The cleanliness of the sealing elements should be checked. Dimensions of the groves must be checked according to sealing element supplier advices.
- All the sealing elements should be installed after being oiled with system oil.
- Installation tools with sharp edges should not be used.
- Uncontrolled heating of sealing elements before fitting is ruther dangerous.
- In case of carrying out final procedures (ie. Painting), the heat over 80ºC should be avoided.

1.2.9 Storage advices for hydraulic and pneumatic sealing elements

Storage of sealing components may bring about to chemical and physical changes. This could be caused by combined factors.

- Oxygen
- Ozone
- Direct sun light
- High temperature
- Ultra violet rays
- Humidity

Stored in good conditions, polyurethane materials can keep their chemical and physical features in long periods.

Environment, moisture and temperature;

Ideal temperature for storage of sealing elements is between 5°C and 25°C and moisture rate should be about 60%. In addition to those direct heat contacts are not recommended.

Dirt;

It may change the mechanical features of products. Therefore, before storage environment must be cleaned out.

Oxygen and ozone;

They are oxidizing agents like oxygen. Ozone is especially a destroying agent.

Deformation;

Deformation should be avoided during storage. Rubber parts and thermoplastic seals should be kept away from coercive forces and squeezing because they cause a rapid change in mechanical features and endurance against agents in nature.

Contact with grease and hydraulic liquids;

Any contact with solvents, oils and other liquids should be avoided.

1.2.10 Importance of choosing the right material for sealing elements

For a sealing element, maybe the most important factor is material. Even if sealing element type is a right choice, sealing performance is determined according to sealing element material. Some of the materials are suitable for high velocities, some of them are suitable for high pressures and some of them are suitable for high temperatures. The first step of choosing the right material is determining the conditions of hydraulic or pneumatic cylinder. If the designer ignores the conditions of operating environment during the choosing the seal, sealing element will fail in short term. The biggest example of this situation is Challenger space shuttle.

In January 28, 1986, Challenger space shuttle disaster was attributed to the malfunctioning of an o - ring. After 73 seconds of Challenger’s launch, a viton o - ring which had been designed to separate the sections of the rocket boosters, had failed due to cold temperatures on the morning of the launch. After blowing up of Challenger with seven crew, investigation revealed that the o-ring seal on Challenger’s solid rocket booster, which had become brittle in the cold temperatures, failed. Flames then broke out of the booster and damaged the external 2 million liter of fuel fulled tank, in causing the spacecraft to disintegrate [8].

Figure 1.27: Challenger space shuttle in 1986 [8].

Maybe, the sealing elements are the cheapest parts of the hydraulic and pneumatic systems, but as in the example, system does not matter without a proper sealing element and material.

For choosing the material of sealing element for an application, acronym "TEMP" can be used.

"**T**" is for temperature;

All of the elastomer, thermoset and thermoplastic materials offer an operating temperature range. That is why choosing of the material must be optimized selection. Some of the seal materials and operation temperature ranges are given in Figure 1.28.

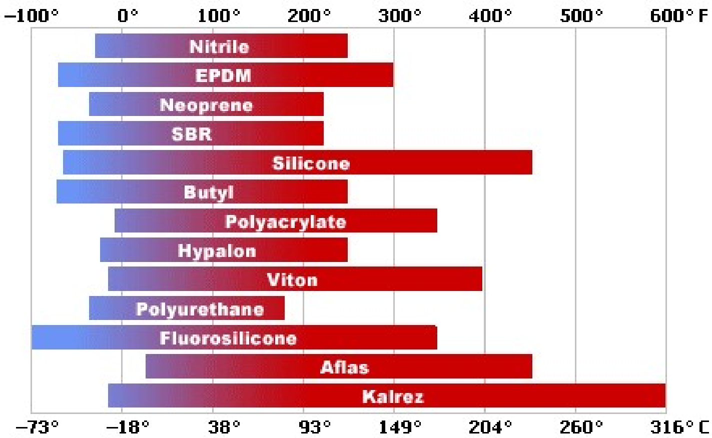


Figure 1.28: Operating temperatures of sealing elements materials [9].

"**E**" is for environment;

Life time cycle of the sealing element is predicted according to environment temperature, humidity and chemical effects. All of the environment conditions must be appropriate for sealing element material.

Seal “**M**” is for media;

There are hundreds of different sealing element materials. Hydraulic and pneumatic sealing element sector needs all of these materials because there are many different medias used in hydraulic or pneumatic cylinders. Sealing element material shall not be degraded after exposing the fluid media. Chemical compatibility guide is given in Appendix A.1.

“P” is for pressure;

System pressure is an important criterion to determine the cylinder design like thickness of bore, cylinder steel material and sealing element geometry and material. System pressure and media type of hydraulic cylinder specifies the sealing element design.

1.3 Thermoplastic polyurethane material

Thermoplastic polyurethane (TPU) is a inimitable grade of plastic created when a polyaddition reaction occurs between a diisocyanate and one or more diols.

Initially created in 1937, this adaptable polymer is delicate and processable when warmed, hard when cooled and equipped for being reprocessed various circumstances without losing basic uprightness. Used either as a malleable engineering plastic or as a replacement for hard rubber, TPU is renowned for many things including its: high elongation and tensile strength; its elasticity; and to varying degrees, its ability to resist oil, grease, solvents, chemicals and abrasion [10].

A wide range attributes offered by TPU are make this material well known over a range markets and applications. TPU is characteristically adaptable and it can be expelled or infusion shaped on conventional thermoplastic assembling hardware to make strong segments.

Principally there are three substance classes of thermoplastic polyurethane;

- **Polyether TPUs** are the greatest compound class of TPU. This sort of TPU has marginally lower gravity than other two chemical classes. Polyether TPU offers low temperature adaptability, hydrolysis resistance and great abrasion and tear strength that are really important parameters for a sealing element material.

- **Polyester TPUs** is the second biggest class of TPU. The most vital property of this class is being compatible with PVC and other polar plastics. Properties are unaffected by oils and chemicals, provide excellent abrasion resistance and offer good physical properties.

- **Polycaprolactone TPUs** have the inherit toughness and resistance of polyester based TPUs combined with low temperature performance and a relatively high resistance to hydrolysis. They are ideal raw material for hydraulic and pneumatic seals [10].

Thermoplastic polyurethane materials can also be subdivided into aromatic and aliphatic varieties;

- **Aromatic TPUs** in lights of isocyanates are workhorse items and can be utilized in applications that require flexibility, strength and toughness.

- **Aliphatic TPUs** in lights of isocyanates are light steady and offer excellent optical clarity. They are usually utilized in interior and exterior applications of automotive sector and as laminating films to bond glass and polycarbonate together in the coating industry.

Thermoplastic polyurethane is a multiphase piece copolymer that is created when three basic raw materials are combined together in a specific way. The components required to produce a thermoplastic polyurethane are;

- A polyol or long chain diol
- A chain extender or short chain diol
- A di isocyanate

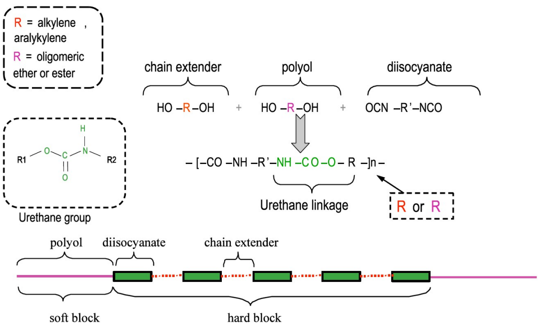


Figure 1.29: Chemical structure of thermoplastic polyurethane.

The smooth block, consisting of a polyol and an isocyanate, is in charge of for the resilience and elongation of a TPU. The strong block, built from a chain extender and isocyanate, gives a TPU its toughness and physical performance properties.

Thermoplastic materials have no chemical cross links unlike thermoset rubbers. Figure 1.30 demonstrates how physical cross links melt out under heat and repack when the material is cooled. This physical cross link gives reprocessable property to the thermoplastic material.

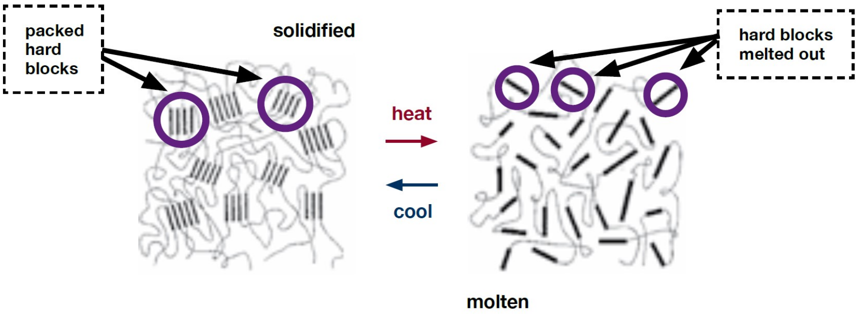


Figure 1.30: Morphology of a thermoplastic polyurethane.

The physical properties of thermoplastic polyurethane depend on the structure of the backbone. They can be tailored to have flexibility, hardness, high strength.

1.4 Additives

For ensuring the intended properties on thermoplastic polyurethane, compounded additives are listed below.

1.4.1 Boron nitride (BN)

Henze HeBoFill 511 powder was used as boron nitride additive. HeBoFill 511 boron nitride powder is the appropriate filler for plastic materials. Typical values of HeBoFill 511 are detailed below.

Table 1.4: Datasheet values of BN [12].

Properties	Value	Unit
Color	white	-
Purity	98.5	%
Oxygen	1.3	%
Boron Oxide	0.2	%

Spec. Surf. Area	14	m^2/g
Median Grain Size	10	μm

Boron nitride is a chemical compound with the BN chemical formula that discovered in the early 19th century was not developed as a commercial material until the latter half of the 20th century [13]. This compound consists of equal numbers of boron and nitrogen atoms. Hexagonal form of BN corresponds to graphite is the most stable and softest among BN polymorphs, and is therefore used as a lubricant. Boron nitride has thermal and chemical stability. Boron nitride can be synthesized in hexagonal and cubic forms.

Hexagonal Boron Nitride (h-BN)

- Excellent lubricating properties
- Machinable using conventional metal cutting techniques
- High dielectric breakdown strength
- High volume resistivity
- Good chemical inertness

Cubic Boron Nitride (c-BN)

- Second hardest material known, inferior only to diamond
- High thermal conductivity
- Excellent wear resistance
- Good chemical inertness

Figure 1.31: Boron nitride powder.

In this study, HeBoFill® 511 Boron nitride powder is used for obtaining the intended properties. Due to the high purity, low density and the intrinsic high thermal conductivity, boron nitride is the appropriate filler for plastic materials in order to increase their heat transfer capability.

1.4.2 Polytetrafluoroethylene (PTFE)

In this study, 3M Dyneon TF9205 is used as PTFE filler. This additive was kindly provided by Kastaş Sealing Technologies.

Polytetrafluoroethylene (PTFE) is a synthetic fluoropolymer of tetrafluoroethylene that discovered in 1938. Polytetrafluoroethylene, or PTFE, is made of a carbon backbone chain, and each carbon has two fluorine atoms attached to it.

Figure 1.32: Polytetrafluoroethylene.

PTFE is a vinyl polymer and its structure is similar to polyethylene. Polytetrafluoroethylene is made from the monomer tetrafluoroethylene by free radical vinyl polymerization. One of the most well-known PTFE brands is Teflon produced by DuPont Corporation.

PTFE is a well known material with the properties of extremely low coefficient of friction, high thermal stability, high electrical resistance and strength of corrosive environments. 3M Dyneon TF9502 properties are detailed below.

Table 1.5: Datasheet values of PTFE [14].

Properties	Test Method	Value	Unit
Average Particle Size	ISO 13321	20	µm

Bulk Density	ASTM D4895	400	g/l
Specific Surface Area	DIN 66132	2	m^2/g
Melting Peak Temperature	ASTM D4591-97	325	°C
Melt Flow Rate*	*	12	g/10min
Melt Viscosity	Median Grain Size	10^2	Pa.S

*The measurements are carried out at 372°C (701°F) (test weight 2.16 kg, die diameter 1.0 mm).

1.4.3 Molybdenum disulfide (MoS_2)

Molybdenum disulfide is the inorganic compound with the formula MoS_2. It is composed of only two elements; molybdenum and sulfur. MoS_2 is relatively unreactive. It is unaffected by dilute acids and oxygen. In appearance, molybdenum disulfide is similar to graphite. It is widely used as a solid lubricant because of its low friction properties and robustness.

Figure 1.33: Molybdenum disulfide.

In this study, ORAPI OR05 is used as MoS_2. This additive was kindly provided by Kastaş Sealing Technologies. Specific properties of this material are presented below.

Table 1.6: Datasheet values of MoS_2 [15].

Properties	**Value**	**Unit**
Color	black	-
Crystalline structure	Hexagonal	-
Average granulometry	2	micron
Specific surface	0.35	m^2/g
Operating temperature range in the air	-200 +450	°C

1.4.4 Graphite

Graphite is a crystalline form of carbon, a semimetal, a native element mineral, and one of the allotropes of carbon. Graphite is the most stable form of carbon under standard conditions. Therefore, it is used in thermochemistry as the standard state for defining the heat of formation of carbon compounds. Graphite is an excellent conductor of heat and electricity and it has extremely high natural strength and stiffness compared to other materials. At the same time, it is one of the lightest of all reinforcing agents and has high natural lubricity.

Figure 1.34: Graphite.

Orion Printex 60A is used as graphite. This additive was kindly provided by Kastaş Sealing Technologies. Specific properties of this material are presented below.

Table 1.7: Datasheet values of graphite [16].

Properties	Test Method	Value	Unit
Color	-	black	-
Volatile Matter at 950°C	DIN53552	0.5	%
pH Value	ISO 787-9	10	-
Ash Content	ASTM D1506	0.1	%
Average Primary Particle Size	TGZ3	21	µm

2. MATERIALS AND METHOD

2.1 Materials

In this study, Lubrizol D11H95S thermoplastic polyurethane material is used as a base material. The neat TPU was kindly provided by Kastaş Sealing Technologies. This material will be referring to as neat TPU throughout the entire study. Figure 2.1 shows this material.

Figure 2.1: Neat TPU.

Specific properties of this material presented below. Four different additives were compounded with this neat TPU to compare the aimed properties. Each additive is compounded in three different percentages to examine the effect of the additive material ratio in neat TPU. In total, a pure neat TPU and twelve compounded materials are tested.

Table 2.1: Specific properties of neat TPU [11].

Properties	Standard	Value	Unit
Gravity	ISO2781	1.16	g/cm^3
Hardness	ISO868	94	Shore A
Tensile Strength	ISO 527-2/5A/500	47	MPa
Stress at 100% Strain	ISO 527-2/5A/500	10	MPa
Elongation at Break	ISO 527-2/5A/500	540	%
Compression Set	ISO815 22h 100°	28	%

2.2 Method

2.2.1 Preparation of the materials for injection molding process

At the beginning of the injection process, materials were scaled according to ratios detailed in Table 2.1.

Table 2.2: Compounding details of samples.

Sample Name	Additive Type	Compounding Details			
		Dosage (%)	**Additive Weight (gr)**	**Neat Material Weight (gr)**	**Weight in Total (gr)**
Neat TPU	-	-	-	5000	5000
Sample 1	Boron Nitride	0,5	25	5000	5025
Sample 2	Boron Nitride	2	100	5000	5100
Sample 3	Boron Nitride	5	250	5000	5250
Sample 4	PTFE	0,5	25	5000	5025
Sample 5	PTFE	2	100	5000	5100
Sample 6	PTFE	5	250	5000	5250
Sample 7	MoS_2	0,5	25	5000	5025
Sample 8	MoS_2	2	100	5000	5100
Sample 9	MoS_2	5	250	5000	5250
Sample 10	Graphite	0,5	25	5000	5025
Sample 11	Graphite	2	100	5000	5100
Sample 12	Graphite	5	250	5000	5250

After scaling the additives with TPU, material compounds obtained are ready to remanufacture by using co-rotate twin screw extruder in Sisan Masterbatches Company in İstanbul. L/D ratio of the extruder is selected as 44:1. Screw speed is determined as 180 rpm. Zone temperatures of extruder were selected between 180 – 200°C. At the end of the extruder die, materials were cooled with cool water bath. Materials cooled in bath, transferred to pelletizer to obtain pellet type thermoplastic polyurethane.

Figure 2.2: Twin screw extruder.

One of the biggest problems in injection molding process is moisture. For preventing the moisture of the material, materials are dried in oven for 4 hours at 100°C. At the end of this process, materials are packaged and labelled according to compound number. At this step materials are ready for injection process.

2.2.2 Injection molding process

At the beginning of the injection molding process, materials are dried in oven for 2 hours at 100°C to eliminate the moisture.

Figure 2.3: Drying oven for material.

Injection molding process is needed to manufacture the test plaques to carry out the laboratory tests and manufacture the sealing elements coded with Kastaş K22-050 hydraulic rod seal to test the material as a real seal in hydraulic test bench. According to these purposes two different injection molds made from steel were used for each compounded material.

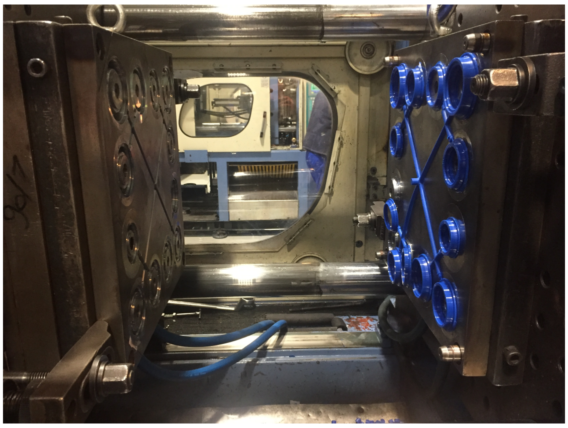


Figure 2.4: Manufacturing test seals in plastic injection machine.

First material will be manufactured; neat thermoplastic polyurethane material was loaded to plastic injection machine hopper. This hopper keeps the material at 100°C during process in case of moisture built up. Injection parameters were determined on machine screen as 175 – 190 °C temperature. The plastic injection machine used for this study is shown in Figure 2.5.

Figure 2.5: Plastic injection machine.

At the end of the injection molding for each material with both mold types, materials were packaged and labelled with material number.

2.2.3 Treatment and sampling materials

At the end of the injection process, test plaques are ready to be tested like tensile test but sealing elements are need one more step to be ready. Usually, sample manufactured by plastic injection process, has injection flashes. After injection process these flashes needed to be cut.

The flashes of manufactured sealing elements are cut to give them to the last form of sealing element. This process is shown in Figure 2.6.

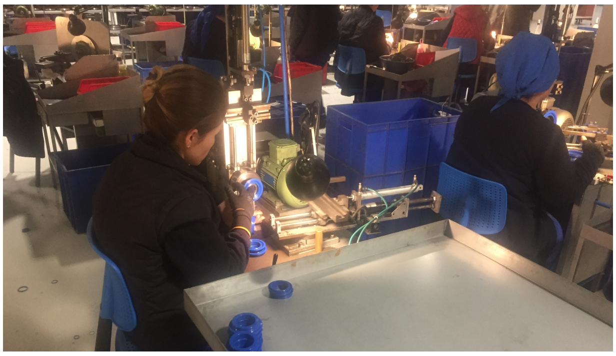


Figure 2.6: Cutting process of sealing elements after injection molding.

After this step, all the manufactured parts are ready to be tested.

2.3 Characterization

2.3.1 Hardness testing

Hardness of the specimens were measured with the help of Bareiss hardness tester in the unit of Shore A. Hardness of the material is an important criterion for sealing elements. The higher hardness value means the better extrusion resistance. Because of this reason, hardness of the compounded materials was measured to control the value changes. Decreasing the harness in the unit of Shore A is not permissible for the material.

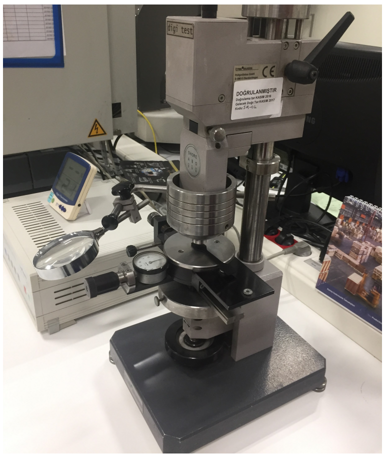


Figure 2.7: Bareiss hardness tester.

2.3.2 Tensile testing

Tensile testing plaques were manufactured in plastic injection machines and these plaques needed to be cut with a blade which has cutting geometry according to ISO37-2. After cutting the plaques with the shape of dumb-bell test pieces, test parameters are determined on computer according to DIN53504. This test standard determines the test speed as 200 mm/min. For each material six specimens were tested to obtain a reliable average of tensile properties. At the end of the tests, elongation at break (%), tensile strength (MPa) and stress at 100% strain (MPa) values are evaluated. Figure 2.8 shows the tensile testing machine used for tests.

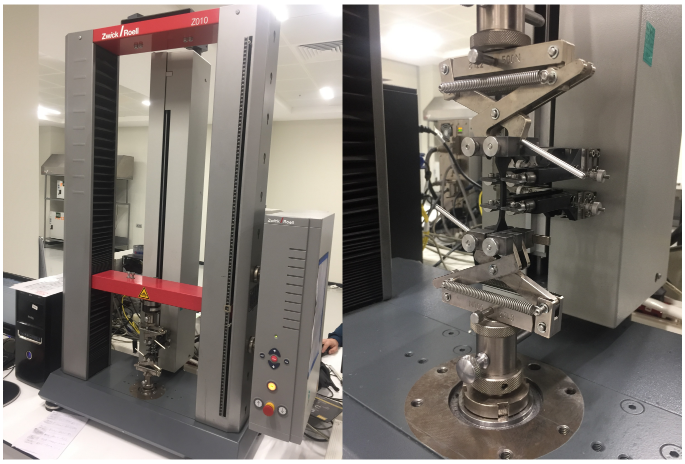


Figure 2.8: Zwick Roel Z10 tensile testing machine.

Tensile tests were performed with Zwick Roell Z10 tensile testing machine in Kastaş Sealing Technologies labs.

2.3.3 Friction force testing

For comparing the friction coefficients of the materials produced from compounded materials, a test rig was designed and produced. Figure 2.9 shows the test rig designed. Test rig simulates the rod sealing element as a real hydraulic cylinder. For this reason, the seal which will be tested, was installed on a groove. Test rod was assembled to the test seal and this rig started to simulate. Two test parameters were measured and reported. First one is assembly force. The other one which is the most important is out-stroke forces after assembly.

Assembly force test was performed to observe the forces during installing the rod to the cylinder. This force depends on rod edge chamfer, tolerances of the metal parts and material of the seals used in design. In the assembly force test, parameters except material of the seals were kept constant. The forces during assemblies were compared. In this study, it is aimed to reduce forces.

Out-stroke force test was performed to observe the forces during movement after installation. The movement of the cylinder is named by examining the relative movement of the rod according to the cylinder tube. If end of the rod getting close to the cylinder bore this movement is called as in-stroke movement of the cylinder. Opposite moving style is called as out-stroke movement of the cylinder. According to seal geometry chosen, out-stroke movement forces are more determinative therefore in this study in-stroke forces were compared to obtain the material friction forces and it is aimed to reduce these forces.

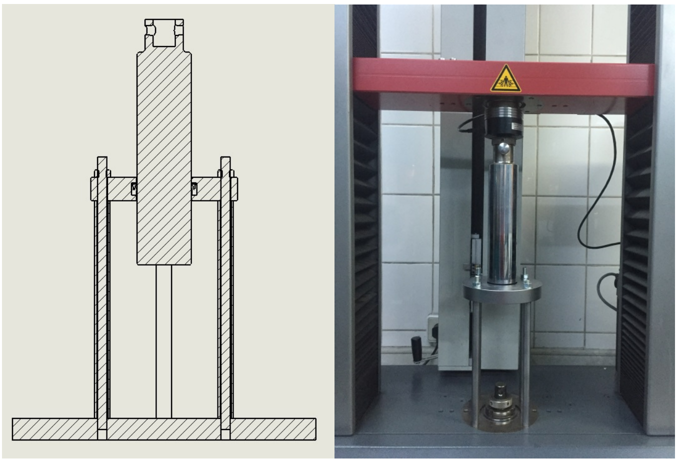


Figure 2.9: Test rig manufactured to compare coefficient of friction.

Test seals manufactured from compounded materials were tested one by one. Figure 2.10 shows how to assembly and disassembly the seals to test groove.

Figure 2.10: Test seal assembly.

After assembly of the test seal, testing software was set to 120 mm stroke, 100 mm/min test speed. During this movement force was measured.

2.3.4 Fourier transform infrared spectroscopy testing (FTIR)

Compounded thermoplastic polyurethane materials were investigated with FTIR analysis. The purpose of Thermo Scientific FTIR analyses is obtaining the spectra of the compounded TPU. Attenuated total reflection infrared (ATR-IR) spectra of the materials were collected at a resolution of 4 cm-1 with a range of 500 – 4000 cm^{-1}. Spectral values were determined in transmittance mode as a function of wave number.

2.3.5 Thermal conductivity coefficient testing

One of the main purposes of this study is increasing the thermal conductivity coefficient of the material. At the end of the manufacturing the compounded materials, thermal conductivity coefficient tests were performed. Test results are determined the thermal conductivity as the unit of Watt / meter * K.

2.3.6 SEM analysis

Scanning electron microscopy was performed to observe the micro structure of the compounded and neat TPU. Zeiss Sigma 300 VP was used to obtain the SEM visuals. SEM images were taken from the test plaques. Firstly, samples were coated with gold and accelerated voltage was adjusted as 5 kV. Images were taken at different magnifications.

2.3.7 Compression set testing

Under the terms of ISO 815, the compressions test value is measured with a constant deformation. Compression set indicated the deformation component of the test material. For the seals, compression set value is an important characteristic parameter. The testing method of compression set is preparing the test specimens and compressing them between two metal parts under certain temperature and designated time. The calculation is performed on the basis of the following formula:

$$CS\ (\%) = (L_0 - L_2) / (L_0 - L_1) \times 100\ \% \tag{2.1}$$

where:

- C_S = Compression set in %
- L_0 = Height of specimen prior to the test
- L_1 = Height of the specimen during the test (spacer)
- L_2 = Height of the specimen after the test

The compression set tests performed in this study, are examined under the conditions of 22 hours and 100°C.

Higher value of compression set result, specifies the worse material.

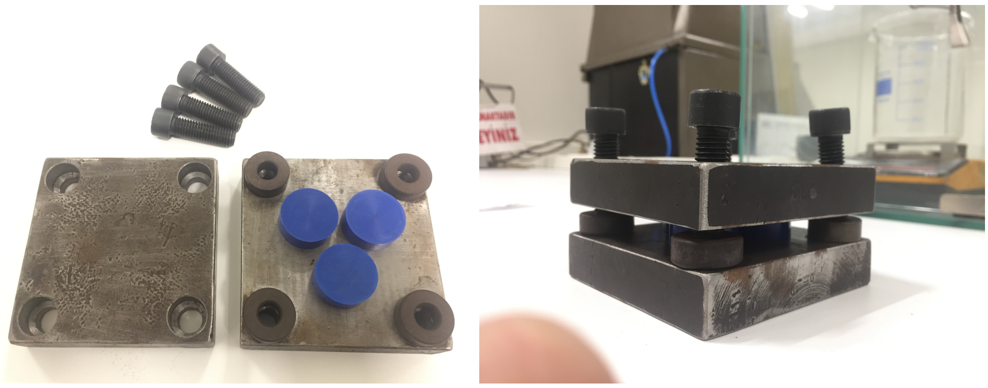


Figure 2.11: Compression set test apparatus.

2.3.8 Hydraulic seal testing on hydraulic seal lifecycle test bench

One of these test rigs in Kastaş Sealing Technologies Labs is hydraulic rod sealing element testing machine which is named TR012013. This test rig has three test cylinders and a drive cylinder with controlled speed and positions. Maximum test pressure is 600 bar which is enforces the standard rod seal. Six rod seals can be tested at the same time in three cylinders. This possibility gives the change of testing the sealing elements under the same test conditions including same speed, same pressure and same temperature. Test cylinders can be climatized between 10°C and 80°C temperature. All the test parameters are defined on touchable screen via PLC controlled electronic cabinet. Test values read from components on the rig, are processing and saving through computer. At the end of the test performed with test rig, values like leakage of the sealing element, temperature history of the rod design, friction force occurring from rod sealing element can be presented.

Figure 2.12: TR012013 Hydraulic rod seal test rig.

3. RESULTS AND DISCUSSIONS

3.1 Hardness testing

Hardness of the thermoplastic polyurethane material for a sealing element is an important parameter to obtain sealing performance according to system pressure hardness of the material changes. In high pressured sealing applications sealing element must be harder to resist extrusion. Particularly in hydraulic applications, the increase in hardness is preferred compared to the reduction in hardness.

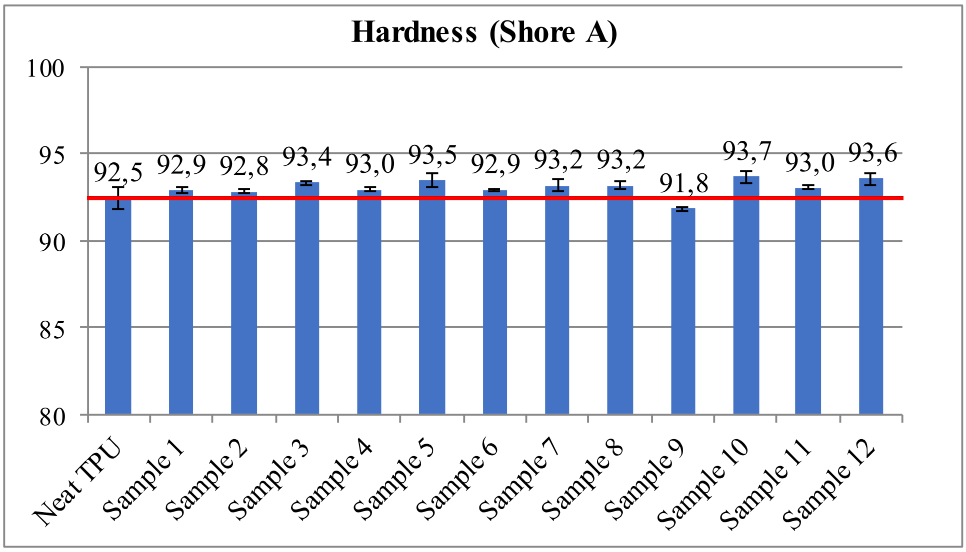


Figure 3.1: Hardness test results.

In this study, hardness of the compounded materials was compared. In the neat TPU, hardness was measured as 92,5 Shore A. This value is a standard hardness for a TPU rod sealing element. In case of higher system pressure, this hardness value can be rise up to 94 – 95 Shore A. This rising can be seen as an advantage.

Determining of the results shows that only hardness value of the Sample 9 was decreased which is not a vital value reduction. The rest of the compounded materials have advantage of hardness increment. Considering that graphite is known by its hardness, samples compounded with graphite have superior hardness values.

Consequently, all of the compounded materials except the Sample 9 became harder in the compare of Neat TPU.

3.2 Tensile testing

The main aim of this study is improving thermal conductivity and coefficient of friction force without causing a loss in mechanical properties. Mechanical properties of the material for a sealing element is crucial. Basically, tensile test is the most common used and simplest mechanical test to observe amount of force required to elongate specific materials to breaking point. In the sealing industry, tensile test is needed to ensure the sealing element is strong enough not to break accidentally. Tensile test of the thermoplastic material ensures that the correct materials, temperatures and duration of sealing process are combined to seal packages effectively and according to relevant standards.

In this study, decreasing of elongation at break and tensile strength can’t be evaluated as successful. Besides improving the thermal conductivity and coefficient of friction, increasing of the mechanical properties of the material, specially elongation at break and tensile strength causes to performance improvement. Neat thermoplastic polyurethane’s mechanical properties are marked with red line in graphs. Tensile test results with deviations are shown in Table 3.1 which located below.

Table 3.1: Tensile test results.

Samples	**Elongation at Break (%)**	**Modulus 100%**	**Tensile Strength (Mpa)**
Neat TPU	670±52.91	11.13±0.4	33.76±3.87
Sample 1	770±26.45	10.9±0.26	42.53±3.67
Sample 2	790±40	11±0.09	45.63±2.19
Sample 3	810±70	11.23±0.2	43±5.2
Sample 4	796.66±35.11	10.8±0.1	49.13±0.87
Sample 5	736.66±70.23	10.96±0.05	38.8±5.52
Sample 6	773.33±40.41	10.36±0.23	42.3±4.71
Sample 7	740±60.82	11.7±0.1	41.7±2.25
Sample 8	693.33±51.31	10.96±0.05	32.9±1.83
Sample 9	693.33±57.73	11.66±0.32	37.2±4.37
Sample 10	696.66±15.27	11.93±0.15	39.9±2.45
Sample 11	673.33±80.82	11.53±0.25	36.76±5.91
Sample 12	596.66±83.26	11.93±0.28	30.9±4.82

When elongation at break results are examined, compounded materials with the additives boron nitride (Sample 1 – Sample 3) and polytetrafluoroethylene (Sample 4 – Sample 6) have better elongation values. Increasing of elongation at break value is really important advantage for resisting against extrusion of the material.

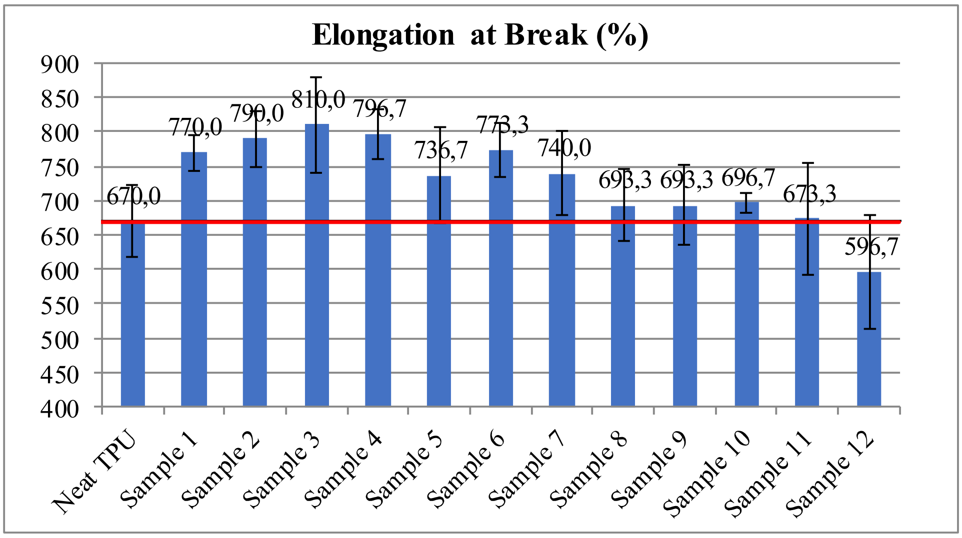


Figure 3.2: Elongation of break test results.

When stress at 100% strain results are examined, all of the results are nearly same. There is no considerable difference among the results. Materials at the same elongation values will give a value of tension that will produce approximately the same force. It would be more reliable to consider tensile strength values instead of stress at 100% strain results.

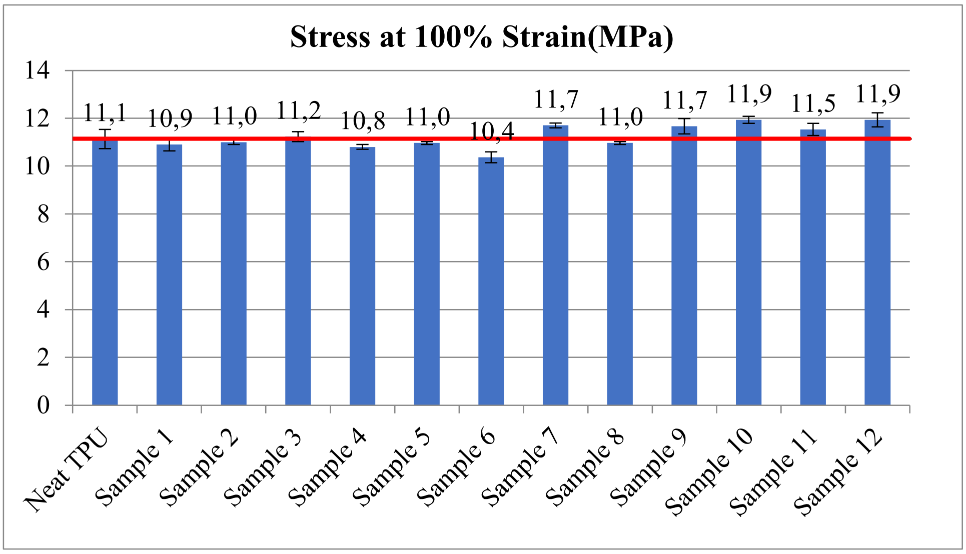


Figure 3.3: Stress at 100% strain test results.

When tensile strength results are examined, which is the most critical, it is clearly seen that compounding of the thermoplastic material with different additives at different ratios changes the tensile strength. As a result of the evaluation of the test result values, it is shown that materials except Sample 8 and Sample 12 have better tensile strength.

At the first three materials, which used additive as boron nitride, tensile strength values are clearly increased. The ratio of the compound changes the tensile strength values. It can be said that the best ratio for the boron nitride is 2%. At the second three materials, which used additive as PTFE, especially compounded material with the ratio of 0,5% has the highest tensile strength among all the results. At the last six materials, which used additive as MoS_2 and Graphite, results are acceptable except Sample 8 and Sample 12 with no great advantage.

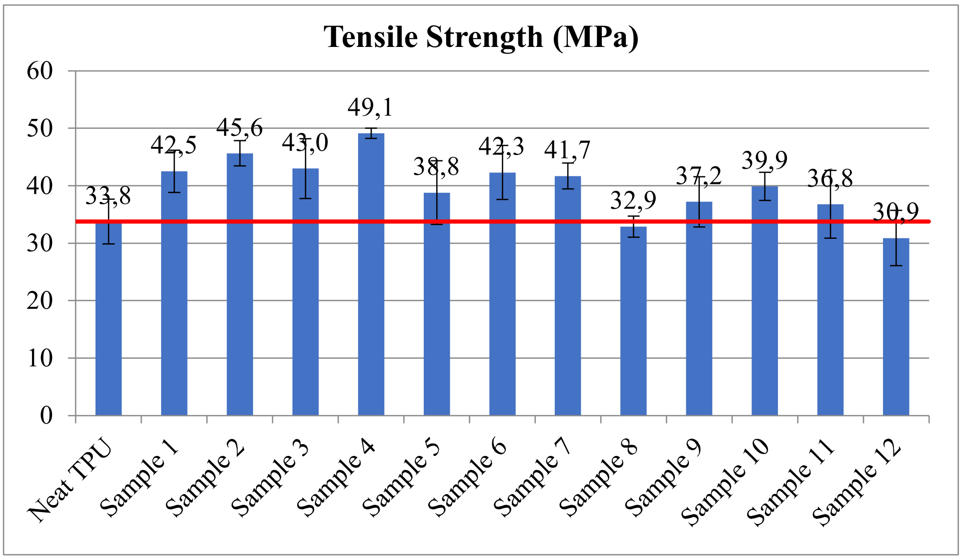


Figure 3.4: Tensile strength test results.

Consequently, tensile test results show that compounding the thermoplastic polyurethane with specified additives improve tensile properties along with targeted properties.

3.3 Friction force testing

Friction force testing is the most determinative test of this study for comparing the coefficient of frictions. This test was performed in two steps as mentioned above. The first test is out-stroke force test which is measuring forces after assembly of the cylinder rod. The same test conditions provided for all the test samples. Comparing the out-stroke forces gives us the force occurred between rod and the sealing element.

When out-stroke forces in average are examined, neat material has 36,39 N force of friction. After compounding the materials with additives mentioned above, especially materials compounded with boron nitride and PTFE have clearly better values. Sample 1, Sample 2, Sample 4 and Sample 6 have the lowest friction forces among all the materials. Figure 3.5 shows the average values of friction forces measured.

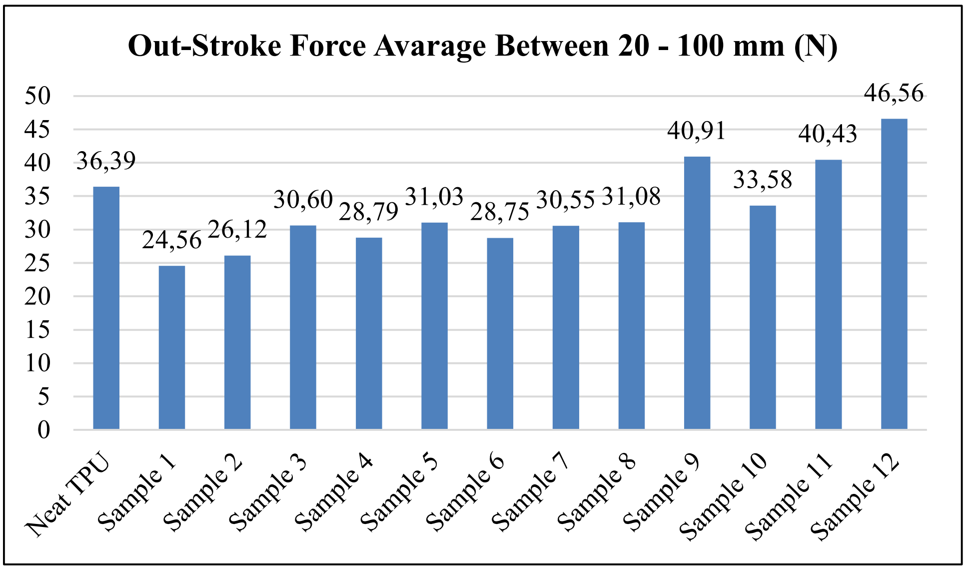


Figure 3.5: Out-stroke friction forces in average.

Before examining the assembly forces, some of the test details must be focused on. According to test rig which designed to measure the assembly force, the strain point at assembly is 9,60 mm. Assembly is performed at this exact point. So, Figure 3.6 shows the strains between 9,4 – 9,8 mm.

When assembly forces are examined, stock material has the highest assembly force which means all the materials used for compounding decreases the assembly force. Especially Sample 6, 8, 10, 11 and 12 have better assembly force results compared to neat material.

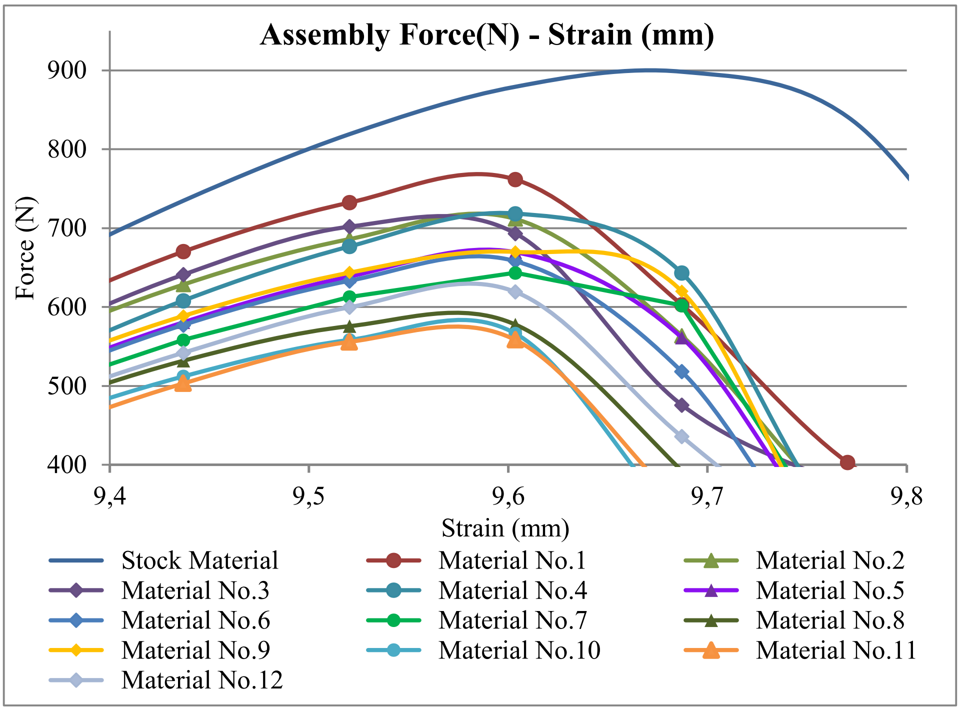


Figure 3.6: Assembly force results.

3.4 Fourier transform infrared spectroscopy testing (FTIR)

Figure 3.7 shows the stacked spectra of Neat and compounded TPU materials between the wave numbers 4000 and 500 cm^{-1}. FTIR spectra of neat TPU showed that TPU has peaks at 3300, 2850, 1701 -1728, 1632 and 1528 cm^{-1}. The peak at 3300 cm^{-1} is N - H stretch. Peak of 2850 is C - H bonding. The peak at 1701 - 1728 cm^{-1} is C = O stretching and it showed urethane linkage formulation of TPU. Graphic shows a strong peak at 1632 cm^{-1} consistent with the stretch of a urea carbonyl group hydrogen- bonded in a bidentate configuration [17].

PTFE has peaks at 1211 cm^{-1} which are are stretching vibrations of CF2. Boron nitride sample has characteristic peaks at 1400 cm^{-1} which are assigned to the B – N stretching vibrations. The examining of the spectra of graphite shows that there is no significant peaks in result. MOS_2 has peaks at 3300 cm^{-1} which are N – H stretch. Due to low additive concentration, there is no significant peak changes observed in compounded material spectras.

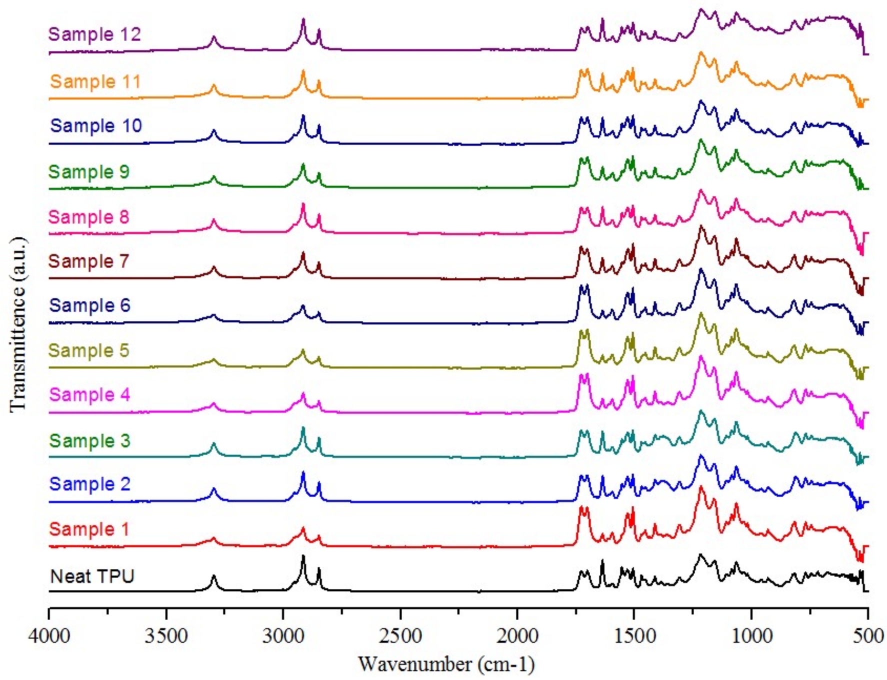


Figure 3.7: FTIR spectra of neat and compounded TPU's.

3.5 Thermal conductivity coefficient testing

One of the main purpose of this study is increasing the thermal conductivity coefficient therefore the most important results for this study is this part. When results are examined, it is seen that neat material has 0,32 W/mK thermal conductivity coefficient. At the first three materials, which are compounded with boron nitride have the same value with the neat material which means boron nitride has not contributed to the increase in thermal conduction. The results are shown in Figure 3.8.

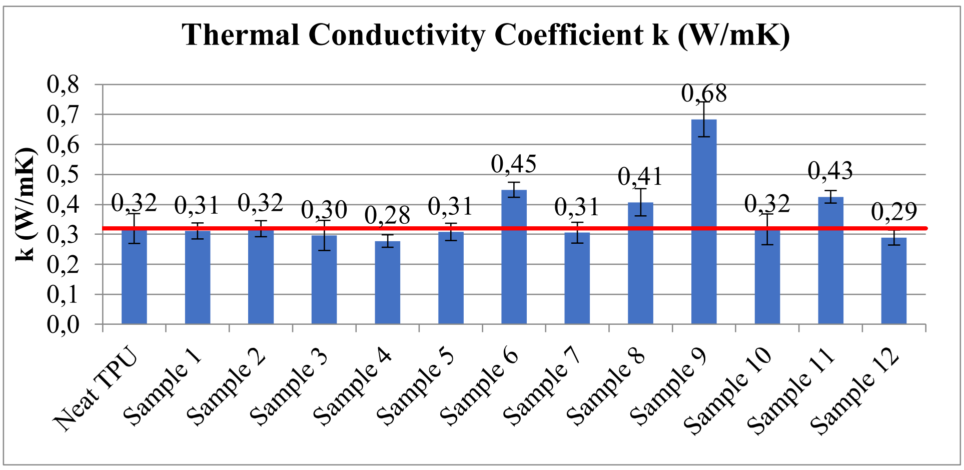


Figure 3.8: Thermal conductivity test results.

Sample 9 which is the compound of thermoplastic polyurethane with MoS_2 with the ratio of %5 has the best value of thermal conductivity coefficient. Sample 6 which is the compound of thermoplastic polyurethane with PTFE with the ratio of %5 has the second good result of thermal conductivity coefficient.

Consequently, result table shows that purpose of increasing the thermal conductivity may be possible with the Sample 6, Sample 9 and Sample 11.

3.6 SEM Analysis

SEM images of Neat TPU, Sample 4, Sample 6, Sample 9 and Sample 11 are shown in Figure 3.9. These samples have been tested because they were performed better in mechanical strength tests and thermal conductivity coefficient test. SEM analysis were performed on test plaques which were manufactured by plastic injection method. Before examining the SEM analysis of the materials, it must be noticed that air bubbles can be observed in images due to moisture or plastic injection method. All of the samples were dried in oven to eliminate the moisture of the material but contacting material with air in short term is a reason to observe air bubbles.

In the Figure 3.9 a, SEM image of Neat TPU is shown. In the figure b, SEM images of Sample 4 which has 0,5 % PTFE as additive is shown. In this image particle of PTFE was observed. The particle size of PTFE changes between 5 – 15 µm. The most crictical point of this image is the PTFE particles in material did not separated from the matrix. This means material must have better tensile strength result. This interference is supported by the tensile strength test. In the Figure 3.9 c, SEM images of Sample 6 which has 5 % PTFE as additive is shown. It is possible to make this inference, as the ratio of PTFE increases; PTFE separates from the TPU matrix. This situation causes the strength to fall. In the Figure 3.9. c SEM images of Sample 9 which has 5 % MoS_2 as additive is shown. MoS_2 has layered structure and it is well attached to the TPU matrix which causes high tensile strength.

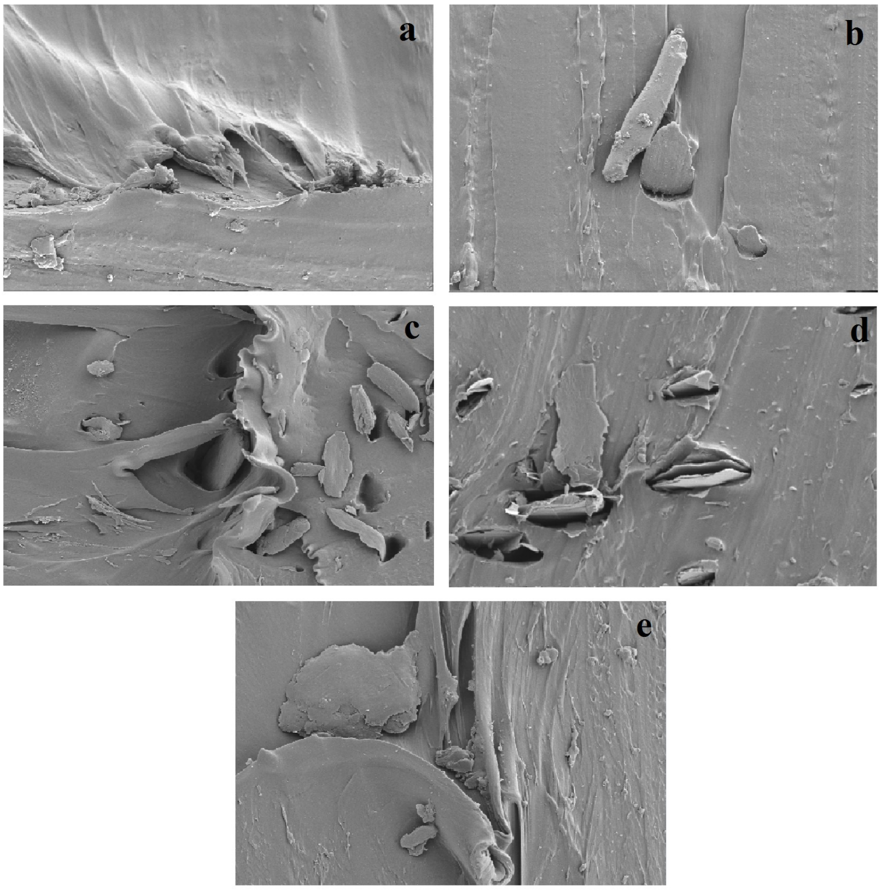


Figure 3.9: SEM images at 2000X; a) Neat TPU, b) Sample 4, c) Sample 6, d) Sample 9 e) Sample 11

3.7 Compression set testing

Compression set value is crucial for a sealing element. It is mostly important in seals which has nutring lip design. If the compression set value is high, force of preloading of the sealing element will decrease in short term. If the compression set value is low, force of preload of sealing element remains stable. Materials used in this study were tested to determine the compression set values. The results are shown in Figure 3.10.

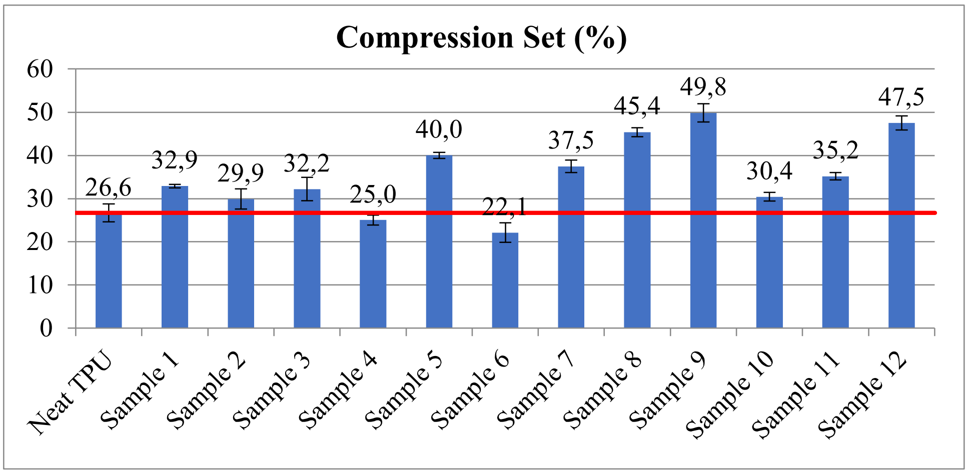


Figure 3.10: Compression set results.

Before examining the results, it should be noted that lower value of compression set means better material for a sealing element. Compression set of the neat material is 26,6% which is the standard value for a sealing element. Decreasing this value besides the targeted properties, will provide an advantage over sealing performance. In the other hand, increasing this value can't be acceptable. The materials which have value higher than 26,6% can't be seen as a suitable material because of the deterioration of the sealing performance.

When the results are examined, Sample 6 and Sample 4 draws attention to compression set value. Especially value of Sample 6 has the best result. This result ensures increasing on the sealing performance in long term which means extended life for a seal.

3.8 Hydraulic seal testing via hydraulic seal lifecycle test bench

After completing the material tests, compounded materials were tested as a real sealing element on the hydraulic test bench. These important tests were kindly performed in Kastaş Sealing Technologies research and development test center. TR012013 named hydraulic rod seal test rig allows to compare friction forces, leakage values and loss of preloads of the test seals.

Testing a rod sealing element for the performance is more determinative than other sealing elements. Therefore, sealing element type that will be tested for this study determined as rod sealing element. To compare the desired properties of the materials, test conditions were adjusted as detailed below. Tests were performed in two stages. First test was performed in 200 bar and the second tests were performed in 315 bar which is highly drastic condition. The only difference between two tests is test pressure. So, leakage values can be compared in different pressures.

Table 3.2: Test parameters

	Condition	Value	Unit
Test Series 1	Speed	0.35	m/s
	Pressure	200	Bar
	Temperature	50	°C
	Extrusion Gap	0.15	mm
	Distance	100	km
Test Series 2	Speed	0.35	m/s
	Pressure	315	bar
	Temperature	50	°C
	Extrusion Gap	0.15	mm
	Distance	100	km

After completing the tests performed in TR012013 named test rig, firstly leakage values were examined. Leakage is highly important for the seal. The first reason of this importance is being environment friendly. The other main reason which is commercial is customer satisfaction.

Original, neat TPU has the 0.0041 ml/100m leakage value. Sample 4, Sample 6 and Sample 10 have better leakage values in the first test series. In the second test series, Sample 10 has higher leakage value in the compare of Neat TPU which means Sample 10 is not suitable for high pressured applications. As a leakage examination Sample 4 and Sample 6 have the best results.

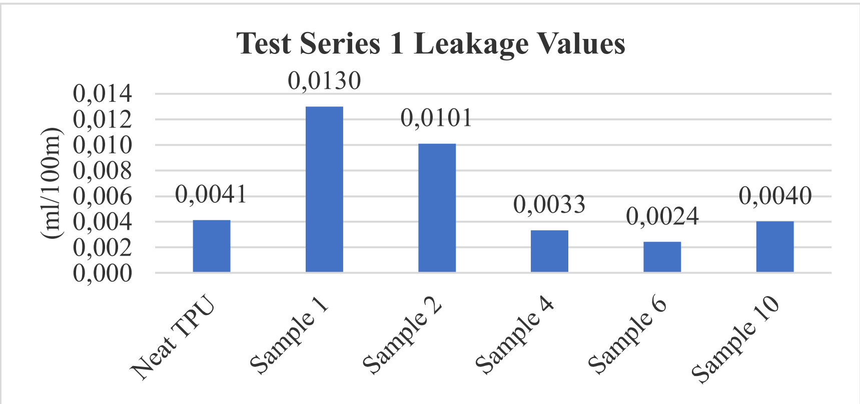


Figure 3.11: Leakage results in the first test series.

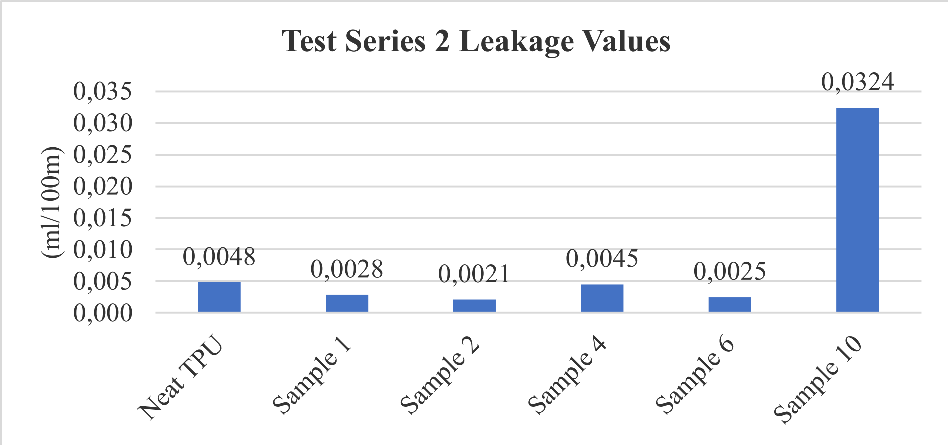


Figure 3.12: Leakage results in the second test series.

The other important examination of these test results is friction forces coming from hydraulic test cylinder. Figure 3.13 and Figure 3.14 illustrate the measured friction forces during the hydraulic tests. Fluctuations in the graphics in all the test series, occur by reason of saving friction forces in different positions of hydraulic cylinder. In both test series, Sample 6 has the best friction force value. This proofs that Sample 6 has lower coefficient of friction than Neat TPU. Compounding the neat material reduces the friction force in the light of information provided by the 3M Dyneon TF9205.

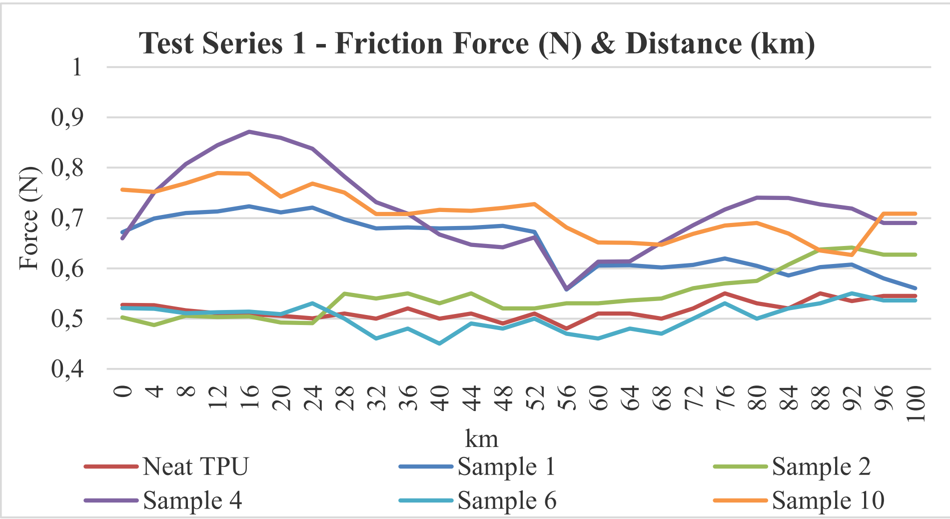


Figure 3.13: Friction forces in test series 1.

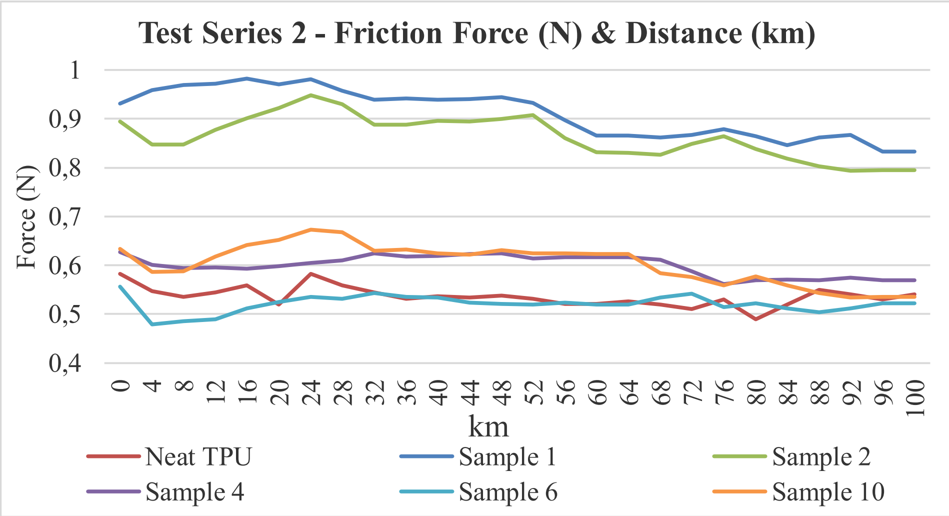


Figure 3.14: Friction forces in test series 2.

At the end of the hydraulic tests, all the sealing elements were tested during 100 km which is approximately 100.000 cycles. This cycle time means nearly 6 - 7 years of service life for an ordinary sealing element. This test duration is sufficient to evaluate the performance of the sealing element.

4. CONCLUSIONS

Four different materials in three different doses each were compounded to obtain desired properties. It is emphasized that the properties that the material possesses should not be impaired when desired properties are obtained. Results of the tests performed are as follows;

According to hardness test and stress at 100% strain there is no significant change observed. The hardness and stress at 100% strain value of the TPU is not affected well or badly. When the elongation at break and tensile tests were examined, it is clearly seen that compounded TPU with boron nitride and PTFE have better results. At the end of the examining the mechanical test results of the materials, it is possible to deduce that using additives as PTFE and boron nitride provide superior mechanical properties, using additives as MOS_2 and graphite does not affect the mechanical test results.

When examining the friction forces, two tests were performed to compare the friction coefficients. The first test is pure friction force after assembly. The other important test for hydraulic and pneumatic sealing sector is assembly force test. The lower the frictional force of the material during assembly, the easier it will be installed by the operator. When these results were examined, all the ratio of PTFE compounded materials have improved friction force values. The best ratio of PTFE additive can be selected as 5% according to friction force tests.

For the compression set test results, neat TPU has 26.6% value which is standard for an ordinary sealing element material. When the other sample results are considered, despite observed improvements on other test results, the compression set test results generally seem to deteriorated except the TPU compounded with PTFE. Especially PTFE compounded TPU with the ratio of 5% gives 17% improvement on compression set value. This improvement will extend the service life of the sealing element besides the expected properties.

According to thermal conductivity coefficient test results, Neat TPU has the value of 0.32 W/mK. Compounded TPU with the MOS_2 additive has the highest thermal conductivity coefficient. Considering other tests such as friction force and compression set, this compound is not appropriate to be a sealing element material. The other compound which has satisfying thermal conductivity coefficient value is TPU with 5% PTFE additive. This compound which is named as Sample 6, has a thermal conductivity coefficient improved by 40 percent compared to neat material.

The SEM tests performed to observe the micro structure of the samples, support the results of tensile tests. The examined details are; separation of additive particles from the TPU matrix and homogenous distribution. It is seen that PTFE has homogenous in size which is nearly 20 µm. Also, the samples produced have air bubbles and proper additive dispersion could not be achieved.

The increase in thermal conductivity is due to decrease in the filler–matrix thermal contact resistance through the improvement of the interface between matrix and particles [18].

Consequently, after the tests performed, 5% PTFE compounded thermoplastic polyurethane material has 40% higher thermal conductivity coefficient and 23% lower coefficient of friction. It can be deducted that the properties intended for the material are gained. For the future of this study, BN and PTFE additives can be compounded together. According to John V. Costa et al, BN particles (5% weight fraction) increased the thermal conductivity of the resulting nanocomposite by 50%, while the increase in thermal conductivity realized by the addition of the silane-treated BN particles was only about 20%. Using both BN and PTFE additives will be more effective to obtain desired properties. Additional analyses for verifying the material could be performed such as long term rod seal life cycle test on a hydraulic machine.

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APPENDIX

Appendix A.1 Chemical compatibility guide for sealing element materials.

Chemical	Nitrile	EPDM	Neoprene	SBR	Silicone	Butyl	Polyacrylate	Hypalon	Viton	Polyurethane	Fluorosilicone	Aflas	Kalrez
Abietic Acid	X	X	X	X	X	X	X	X	X	X	X	X	1
Acetaldehyde	3	2	3	3	2	2	4	3	4	4	4	3	1
Acetamide	1	1	1	4	2	2	4	2	3	4	1	2	1
Acetanilide	3	1	1	1	2	1	4	1	3	4	1	X	1
Acetic Acid, 30%	X	1	X	X	X	X	X	X	X	X	X	X	1
Acetic Acid, 5%	2	1	1	2	1	1	4	1	1	4	2	1	1
Acetic Acid, Glacial	2	1	4	2	1	2	4	3	2	4	2	3	1
Acetic Acid, Hot, High Pressure	4	3	4	4	3	4	4	3	4	4	4	3	1
Acetic Anhydride	3	2	2	2	2	2	4	2	4	4	4	2	1
Acetoacetic Acid	3	1	1	1	2	1	4	1	3	4	1	X	1
Acetone	4	1	4	4	4	1	4	3	4	4	4	2	1
Acetone Cyanohydrin	3	1	1	1	2	1	4	1	3	4	1	X	1
Acetonitrile	3	1	X	X	X	X	X	X	1	X	X	1	1
Acetophenetidine	2	4	4	4	X	4	4	4	1	3	2	X	1
Acetophenone	4	1	4	4	4	2	4	4	4	4	4	2	1
Acetotoluidide	2	4	4	4	X	4	4	4	1	3	2	X	1
Acetyl Acetone	4	1	4	4	4	1	4	4	4	4	4	2	1
Acetyl Bromide	4	1	4	4	4	1	4	4	1	4	4	2	1

Acetyl Chloride	4	4	4	4	4	4	4	4	1	4	1	2	1
Acetylene	1	1	2	2	2	1	4	2	1	4	X	1	1
Acetylene Tetrabromide	4	1	2	4	X	1	X	X	1	4	X	1	1
Acetylene Tetrachloride	4	1	2	4	X	1	X	X	1	4	X	1	1
Acetylsalicylic Acid	2	4	4	4	X	4	4	4	1	3	2	X	1
Acids, Non-organic	X	X	X	X	X	X	X	X	X	X	X	X	1
Acids, Organic	X	X	X	X	X	X	X	X	X	X	X	X	1
Aconitic Acid	X	X	X	X	X	X	X	X	X	X	X	X	1
Acridine	X	X	X	X	X	X	X	X	X	X	X	X	1
Acrolein	3	1	1	1	2	1	4	1	3	4	1	X	1
Acrylic Acid	2	4	4	4	X	4	4	4	1	3	2	X	1
Acrylonitrile	4	4	4	3	4	4	4	3	3	4	4	3	1
Adipic Acid	1	2	X	X	X	X	X	X	X	X	X	2	1
Aero Lubriplate	1	4	1	2	2	4	1	1	1	1	1	2	1
Aero Shell 17 Grease	1	4	2	4	2	4	1	1	1	1	1	2	1
Aero Shell 750	2	4	4	4	4	4	2	4	1	4	2	2	1
Aero Shell 7A Grease	2	4	2	4	2	4	1	1	1	1	1	2	1
Aero Shell IAC	1	4	2	4	2	4	1	1	1	1	1	2	1
Aerosafe 2300	4	1	4	4	3	2	4	4	4	4	3	2	1
Aerosafe 2300W	4	1	4	4	3	2	4	4	4	4	3	2	1
Aerozene 50	3	1	4	4	4	1	X	4	4	4	4	2	2
Air, Below 200° F	2	1	1	2	1	1	1	1	1	2	1	1	1
Air, 200 - 300° F	3	2	2	4	1	2	2	2	1	3	1	1	1
Air, 300 - 400° F	4	4	4	4	1	4	4	4	1	4	2	2	1
Air, 400 - 500° F	4	4	4	4	2	4	4	4	3	4	4	3	2
Aliphatic Dicarboxylic Acid	2	4	4	4	X	4	4	4	1	3	2	X	1

Alkanes (Paraffin Hydrocarbons)	1	4	2	4	2	4	1	2	1	1	1	X	1
Alkanesulfonic Acid	1	4	2	4	2	4	1	2	1	1	1	X	1
Alkazene	4	4	4	4	4	4	4	4	2	4	2	2	1
Alkenes (Olefin Hydrocarbons)	2	4	4	4	X	4	4	4	1	3	2	X	1
Alkyl Acetone	3	1	1	1	2	1	4	1	3	4	1	X	1
Alkyl Alcohol	1	4	2	4	2	4	1	2	1	1	1	X	1
Alkyl Amine	1	4	2	4	2	4	1	2	1	1	1	X	1
Alkyl Aryl Sulfonates	1	4	2	4	2	4	1	2	1	1	1	X	1
Alkyl Aryl Sulfonics	1	4	2	4	2	4	1	2	1	1	1	X	1
Alkyl Benzene	2	4	4	4	X	4	4	4	1	3	2	X	1
Alkyl Chloride	2	4	4	4	X	4	4	4	1	3	2	X	1
Alkyl Sulfide	2	4	4	4	X	4	4	4	1	3	2	X	1
Alkylnaphthalene Sulfonic Acid	1	4	2	4	2	4	1	2	1	1	1	X	1
Allyl Chloride	2	4	1	X	X	X	X	X	1	X	X	X	1
Allylidene Diacetate	3	1	1	1	2	1	4	1	3	4	1	X	1
Alpha Picoline	3	1	1	1	2	1	4	1	3	4	1	X	1
Aluminum Acetate	2	1	2	2	4	1	4	4	4	4	4	2	1
Aluminum Bromide	1	1	1	1	1	1	1	1	1	3	1	1	1
Aluminum Chlorate	3	1	1	1	2	1	4	1	3	4	1	X	1
Aluminum Chloride	1	1	1	1	2	1	1	1	1	3	1	1	1
Aluminum Ethylate	X	X	X	X	X	X	X	X	X	X	X	X	1
Aluminum Fluoride	1	1	1	1	2	1	X	1	1	3	1	1	1
Aluminum Fluorosilicate	X	X	X	X	X	X	X	X	X	X	X	X	1
Aluminum Formate	3	1	1	1	2	1	4	1	3	4	1	X	1
Aluminum Hydroxide	2	1	X	X	2	X	X	X	2	X	X	1	1
Aluminum Linoleate	1	4	2	4	2	4	1	2	1	1	1	X	1

Aluminum Nitrate	1	1	1	1	2	1	X	1	1	3	X	1	1
Aluminum Oxalate	3	1	1	1	2	1	4	1	3	4	1	X	1
Aluminum Phosphate	1	1	1	X	2	X	X	X	1	X	X	1	1
Aluminum Potassium Sulfate	3	1	1	1	2	1	4	1	3	4	1	X	1
Aluminum Salts	1	1	1	1	1	1	1	1	1	3	1	1	1
Aluminum Sodium Sulfate	3	1	1	1	2	1	4	1	3	4	1	X	1
Aluminum Sulfate	1	1	1	2	1	1	4	1	1	4	1	1	1
Alums-NH3 -Cr -K	1	1	1	1	1	1	4	1	4	X	4	2	1
Ambrex 33 (Mobil)	1	4	2	4	4	4	1	3	1	2	3	2	1
Ambrex 830 (Mobil)	1	3	2	4	2	3	1	2	1	1	1	2	1
Amines-Mixed	4	2	2	2	2	2	4	4	4	4	4	3	2
Aminoanthraquinone	X	X	X	X	X	X	X	X	X	X	X	X	1
Aminoazobenzene	X	X	X	X	X	X	X	X	X	X	X	X	1
Aminobenzene Sulfonic Acid	X	X	X	X	X	X	X	X	X	X	X	X	1
Aminobenzoic Acid	X	X	X	X	X	X	X	X	X	X	X	X	1
Aminopyridine	X	X	X	X	X	X	X	X	X	X	X	X	1
Aminosalicylic Acid	X	X	X	X	X	X	X	X	X	X	X	X	1
Ammonia (Anhydrous)	2	1	1	4	2	1	4	4	4	4	4	2	2
Ammonia and Lithium Metal in Solution	2	2	X	4	4	2	4	4	4	4	4	3	4
Ammonia, Gas, Cold	1	1	1	1	1	1	4	1	4	X	4	2	1
Ammonia, Gas, Hot	4	2	2	4	X	2	4	2	4	X	4	2	2
Ammonia, Liquid (Anhydrous)	2	1	1	4	2	1	4	2	4	4	4	2	2
Ammonium Acetate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Arsenate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Benzoate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Bicarbonate	3	1	1	1	2	1	4	1	3	4	1	X	1

Ammonium Bisulfite	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Bromide	1	1	1	1	X	1	X	1	1	1	X	1	1
Ammonium Carbamate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Carbonate	4	1	1	1	X	1	4	1	1	4	X	1	1
Ammonium Chloride, 2N	1	1	1	1	X	1	X	1	1	1	X	1	1
Ammonium Citrate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Dichromate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Diphosphate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Fluoride	1	1	1	1	X	1	X	1	1	1	X	1	1
Ammonium Fluorosilicate	X	X	X	X	X	X	X	X	X	X	X	X	1
Ammonium Formate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Hydroxide, 3 Molar	1	1	1	2	1	1	4	1	3	4	1	2	2
Ammonium Hydroxide, Concentrated	4	1	1	3	1	1	4	1	4	4	1	2	2
Ammonium Iodide	1	1	1	1	X	1	X	1	1	1	X	1	1
Ammonium Lactate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Metaphosphate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Molybdenate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Nitrate, 2N	1	1	1	1	X	1	2	1	X	X	X	2	X
Ammonium Nitrite	1	1	1	1	2	1	X	1	X	X	X	2	1
Ammonium Oxalate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Perchlorate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Perchloride	X	X	X	X	X	X	X	X	X	X	X	X	1
Ammonium Persulfate 10%	4	1	1	4	X	1	4	X	X	4	X	2	X
Ammonium Persulfate Solution	4	1	X	4	X	1	4	X	X	4	X	2	1
Ammonium Phosphate	1	1	1	1	1	1	X	1	4	X	X	2	1
Ammonium Phosphate, Dibasic	1	1	1	1	1	1	X	1	X	X	X	2	1

Ammonium Phosphate, Mono-Basic	1	1	1	1	1	1	X	1	X	X	X	2	1
Ammonium Phosphate, Tribasic	1	1	1	1	1	1	X	1	X	X	X	2	1
Ammonium Phosphite	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Picrate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Polysulfide	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Salicylate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Salts	1	1	1	1	1	1	3	1	3	X	3	2	1
Ammonium Sulfamate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Sulfate	1	1	1	2	X	1	4	1	4	X	X	2	1
Ammonium Sulfate Nitrate	1	1	1	2	X	1	4	1	4	X	X	2	1
Ammonium Sulfide	1	1	1	2	X	1	4	1	4	X	X	2	1
Ammonium Sulfite	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Thiocyanate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Thioglycolate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Thiosulfate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Tungstate	3	1	1	1	2	1	4	1	3	4	1	X	1
Ammonium Valerate	3	1	1	1	2	1	4	1	3	4	1	X	1
Amyl Acetate	1	3	4	4	4	3	4	4	4	4	4	3	1
Amyl Alcohol	2	1	2	2	4	1	4	2	2	4	1	1	1
Amyl Borate	1	4	1	4	X	4	X	1	1	X	X	2	1
Amyl Butyrate	1	4	2	4	2	4	1	2	1	1	1	X	1
Amyl Chloride	X	4	4	4	4	4	4	4	1	X	2	2	1
Amyl Chloronaphthalene	4	4	4	4	4	4	4	4	1	X	2	2	1
Amyl Cinnamic Aldehyde	2	4	4	4	X	4	4	4	1	3	2	X	1
Amyl Laurate	2	4	4	4	X	4	4	4	1	3	2	X	1
Amyl Mercaptan	2	4	4	4	X	4	4	4	1	3	2	X	1

Amyl Naphthalene	4	4	4	4	4	4	2	4	1	4	1	2	1
Amyl Nitrate	3	1	1	1	2	1	4	1	3	4	1	X	1
Amyl Nitrite	3	1	1	1	2	1	4	1	3	4	1	X	1
Amyl Phenol	X	X	X	X	X	X	X	X	X	X	X	X	1
Amyl Propionate	1	4	2	4	2	4	1	2	1	1	1	X	1
Anderol, L- 826 (di-ester)	2	4	4	4	4	4	2	4	1	4	2	2	1
Anderol, L- 829 (di-ester)	2	4	4	4	4	4	2	4	1	4	2	2	1
Anderol, L-774 (di-ester)	2	4	4	4	4	4	2	4	1	4	2	2	1
ANG-25 (Di-ester Base) (TG749)	2	4	4	4	2	4	2	4	1	4	2	2	1
ANG-25 (Glyceral Ester)	2	1	2	2	2	2	4	2	1	4	2	1	1
Aniline	4	2	4	4	4	2	4	4	3	4	3	2	1
Aniline Dyes	4	2	2	2	3	2	4	2	2	4	2	2	1
Aniline Hydrochloride	2	2	4	3	3	2	4	4	2	4	2	2	1
Aniline Oil	4	2	4	4	4	2	4	4	3	4	3	2	2
Aniline Sulfate	3	1	1	1	2	1	4	1	3	4	1	X	1
Aniline Sulfite	3	1	1	1	2	1	4	1	3	4	1	X	1
Animal Fats	1	2	2	X	X	X	X	X	1	X	X	1	1
Animal Oil (Lard Oil)	1	2	2	4	2	2	1	2	1	2	1	2	1
Anisole	X	X	X	X	X	X	X	X	X	X	X	X	1
Anisoyl Chloride	X	X	X	X	X	X	X	X	X	X	X	X	1
AN-O-3 Grade M	1	4	2	4	2	4	1	2	1	1	1	1	1
AN-O-366	1	4	2	4	4	4	1	2	1	1	1	2	1
AN-O-6	1	4	2	4	4	4	1	2	1	1	1	1	1
Ansul Ether 161 or 181	3	3	4	4	4	3	4	4	4	2	3	3	1
Anthracene	2	4	4	4	X	4	4	4	1	3	2	X	1
Anthranilic Acid	X	X	X	X	X	X	X	X	X	X	X	X	1

Anthraquinone	X	X	X	X	X	X	X	X	X	X	X	X	1
Anti-freeze Solutions	3	1	1	1	2	1	4	1	3	4	1	X	1
Antimony Chloride	1	4	2	4	4	4	1	2	1	1	1	1	1
Antimony Pentachloride	1	4	2	4	4	4	1	2	1	1	1	1	1
Antimony Pentafluoride	X	X	X	X	X	X	X	X	X	X	X	X	2
Antimony Sulfate	X	X	X	X	X	X	X	X	X	X	X	X	1
Antimony Tribromide	1	4	2	4	4	4	1	2	1	1	1	1	1
Antimony Trichloride	1	4	2	4	4	4	1	2	1	1	1	1	1
Antimony Trifluoride	1	4	2	4	4	4	1	2	1	1	1	1	1
Antimony Trioxide	1	4	2	4	4	4	1	2	1	1	1	1	1
AN-VV-O-366b Hydr. Fluid	1	4	2	4	4	4	2	2	1	2	1	1	1
Aqua Regia	4	3	4	X	X	X	X	X	2	X	X	3	2
Arachidic Acid	X	X	X	X	X	X	X	X	X	X	X	X	1
Argon	1	1	1	1	1	1	1	1	1	1	1	1	1
Aroclor, 1248	3	2	4	4	2	2	4	4	1	4	2	1	1
Aroclor, 1254	4	2	4	4	3	4	4	4	1	4	2	1	1
Aroclor, 1260	1	X	1	1	1	1	4	1	1	4	1	1	1
Aromatic Fuel -50%	2	4	4	4	4	4	4	4	1	4	2	2	1
Arsenic Acid	1	1	1	1	1	1	3	1	1	3	1	1	1
Arsenic Oxide	X	X	X	X	X	X	X	X	X	X	X	X	1
Arsenic Trichloride	1	4	1	X	X	X	X	X	4	X	X	X	1
Arsenic Trioxide	1	4	1	X	X	X	X	X	4	X	X	X	1
Arsenic Trisulfide	1	4	1	X	X	X	X	X	4	X	X	X	1
Arsenites	X	X	X	X	X	X	X	X	X	X	X	X	1
Arsine	X	X	X	X	X	X	X	X	X	X	X	X	1
Aryl Orthosilicate	X	X	X	X	X	X	X	X	X	X	X	X	1

Ascorbic Acid	3	1	1	1	2	1	4	1	3	4	1	X	1
Askarel Transformer Oil	2	4	4	4	4	4	4	4	1	4	2	2	1
Aspartic Acid	3	1	1	1	2	1	4	1	3	4	1	X	1
Asphalt	2	4	2	4	4	4	2	2	1	2	2	2	1
ASTM Oil, No. 1	1	4	1	4	1	4	1	2	1	1	1	1	1
ASTM Oil, No. 2	1	4	2	4	4	4	1	4	1	2	1	1	1
ASTM Oil, No. 3	1	4	4	4	3	4	1	4	1	2	1	1	1
ASTM Oil, No. 4	2	4	4	4	4	4	2	4	1	4	2	1	1
ASTM Oil, No. 5	1	4	2	X	X	X	X	X	1	X	X	1	1
ASTM Reference Fuel A	1	4	2	4	4	4	2	2	1	1	1	1	1
ASTM Reference Fuel B	1	4	4	4	4	4	4	4	1	2	1	1	1
ASTM Reference Fuel C	2	4	4	4	4	4	4	4	1	4	2	1	1
ASTM Reference Fuel D	2	4	4	X	X	X	X	X	1	X	X	4	1
ATL-857	2	4	4	4	4	4	2	4	1	4	2	1	1
Atlantic Dominion F	1	4	2	4	4	4	1	4	1	2	1	2	1
Atlantic Utro Gear-e	1	4	2	X	X	X	X	X	1	X	X	1	1
Atlantic Utro Gear-EP Lube	1	4	2	4	4	4	1	4	1	1	1	2	1
Aure 903R (Mobil)	1	4	2	4	4	4	1	4	1	1	4	2	1
AUREX 256	X	X	X	X	X	X	X	X	X	X	X	X	1
Automatic Transmission Fluid	1	4	2	4	4	4	1	3	1	2	X	2	1
Automotive Brake Fluid	3	1	2	1	3	2	4	2	4	4	4	2	1
AXAREL 9100	X	X	X	X	X	X	X	X	X	X	X	X	1
Azobenzene	X	X	X	X	X	X	X	X	X	X	X	X	1
Bardol B	4	4	4	4	4	4	4	4	1	4	2	2	1
Barium Carbonate	3	1	1	1	2	1	4	1	3	4	1	X	1
Barium Chlorate	3	1	1	1	2	1	4	1	3	4	1	X	1

Barium Chloride	1	1	1	1	1	1	1	1	1	1	1	1	1
Barium Cyanide	1	1	1	1	1	1	1	1	1	1	1	1	1
Barium Hydroxide	1	1	1	1	1	1	4	1	1	4	1	1	1
Barium Iodide	1	1	1	1	1	1	1	1	1	1	1	1	1
Barium Nitrate	3	1	1	1	2	1	4	1	3	4	1	X	1
Barium Oxide	1	1	1	1	1	1	4	1	1	4	1	1	1
Barium Peroxide	3	1	1	1	2	1	4	1	3	4	1	X	1
Barium Polysulfide	3	1	1	1	2	1	4	1	3	4	1	X	1
Barium Salts	1	1	1	1	1	1	1	1	1	1	1	1	1
Barium Sulfate	1	1	1	X	X	X	X	X	1	X	X	1	1
Barium Sulfide	1	1	1	2	1	1	4	1	1	1	1	1	1
Bayol 35	1	4	2	4	4	4	1	4	1	2	1	2	1
Bayol D	1	4	2	4	4	4	1	4	1	4	1	2	1
Beer	1	1	1	1	1	1	4	1	1	2	1	1	1
Beet Sugar Liquids	1	1	1	X	X	X	X	X	1	X	X	1	1
Beet Sugar Liquors	1	1	2	1	1	1	4	1	1	4	1	1	1
Benzaldehyde	4	1	4	4	2	1	4	1	4	4	4	2	1
Benzaldehyde Disulfonic Acid	X	X	X	X	X	X	X	X	X	X	X	X	1
Benzamide	2	4	4	4	X	4	4	4	1	3	2	X	1
Benzanthrone	2	4	4	4	X	4	4	4	1	3	2	X	1
Benzene	4	4	4	4	4	4	4	4	1	4	3	2	1
Benzene Hexachloride	X	X	X	X	X	X	X	X	X	X	X	X	1
Benzenesulfonic Acid 10%	4	4	2	4	4	4	4	1	1	4	2	2	1
Benzidine	2	4	4	4	X	4	4	4	1	3	2	X	1
Benzidine 3 Sulfonic Acid	2	4	4	4	X	4	4	4	1	3	2	X	1
Benzil	2	4	4	4	X	4	4	4	1	3	2	X	1

Benzilic Acid	2	4	4	4	X	4	4	4	1	3	2	X	1
Benzine (Ligroin)	1	4	2	4	4	4	1	3	1	2	1	2	1
Benzocatechol	2	4	4	4	X	4	4	4	1	3	2	X	1
Benzochloride	4	1	4	4	X	2	4	4	1	X	1	1	1
Benzoic Acid	4	4	4	4	4	4	4	4	1	4	2	2	1
Benzoin	2	4	4	4	X	4	4	4	1	3	2	X	1
Benzonitrile	3	1	1	1	2	1	4	1	3	4	1	X	1
Benzophenone	X	2	X	4	X	2	4	X	1	4	1	2	1
Benzoquinone	X	2	X	4	X	2	4	X	1	4	X	2	1
Benzotrichloride	4	1	4	X	X	X	X	X	1	X	X	1	1
Benzotrifluoride	4	1	4	X	X	X	X	X	1	X	X	1	1
Benzoyl Chloride	X	X	4	4	X	4	4	4	1	3	2	X	1
Benzoyl Peroxide	X	X	X	X	X	X	X	X	X	X	X	X	1
Benzoylsulfonilic Acid	2	4	4	4	X	4	4	4	1	3	2	X	1
Benzyl Acetate	3	1	1	1	2	1	4	1	3	4	1	X	1
Benzyl Alcohol	4	2	2	4	2	2	4	2	1	4	2	2	1
Benzyl Amine	X	X	X	X	X	X	X	X	X	X	X	X	1
Benzyl Benzoate	4	4	4	4	4	2	4	4	1	4	1	2	1
Benzyl Bromide	4	4	4	4	4	4	4	4	1	4	1	2	1
Benzyl Butyl Phthalate	3	1	1	1	2	1	4	1	3	4	1	X	1
Benzyl Chloride	4	4	4	4	4	4	4	4	1	4	1	2	1
Benzyl Phenol	2	4	4	4	X	4	4	4	1	3	2	X	1
Benzyl Salicylate	2	4	4	4	X	4	4	4	1	3	2	X	1
Beryllium Chloride	1	1	3	3	3	1	3	3	1	3	3	1	1
Beryllium Fluoride	1	1	3	3	3	1	3	3	1	3	3	1	1
Beryllium Oxide	1	1	3	3	3	1	3	3	1	3	3	1	1

Beryllium Sulfate	3	1	1	1	2	1	4	1	3	4	1	X	1
Bismuth Carbonate	3	1	1	1	2	1	4	1	3	4	1	X	1
Bismuth Nitrate	3	1	1	1	2	1	4	1	3	4	1	X	1
Bismuth Oxychloride	3	1	1	1	2	1	4	1	3	4	1	X	1
Bittern	X	X	X	X	X	X	X	X	X	X	X	X	1
Black Liquor	2	1	1	X	X	X	X	X	1	X	X	1	3
Black Point 77	1	1	3	3	3	1	3	3	1	3	3	1	1
Blast Furnace Gas	4	4	4	4	1	4	4	4	1	4	2	2	1
Bleach Liquor	3	1	2	3	2	1	4	1	1	4	2	1	1
Bleach Solutions	X	1	X	X	X	X	X	X	1	X	X	X	1
Borax	2	1	4	2	2	1	2	4	1	1	2	1	1
Borax Solutions	X	1	X	X	X	X	X	X	1	X	X	X	1
Bordeaux Mixture	2	1	2	2	2	1	4	1	1	4	2	1	1
Boric Acid	1	1	1	1	1	1	4	1	1	1	1	1	1
Boric Oxide	3	1	1	1	2	1	4	1	3	4	1	X	1
Borneol	2	4	4	4	X	4	4	4	1	3	2	X	1
Bornyl Acetate	2	4	4	4	X	4	4	4	1	3	2	X	1
Bornyl Chloride	2	4	4	4	X	4	4	4	1	3	2	X	1
Bornyl Formate	2	4	4	4	X	4	4	4	1	3	2	X	1
Boron Fluids (HEF)	2	4	4	4	4	4	4	4	1	4	2	2	1
Boron Hydride	X	X	X	X	X	X	X	X	X	X	X	X	1
Boron Phosphate	X	X	X	X	X	X	X	X	X	X	X	X	1
Boron Tribromide	X	X	X	X	X	X	X	X	X	X	X	X	1
Boron Trichloride	X	X	X	X	X	X	X	X	X	X	X	X	1
Boron Trifluoride	X	X	X	X	X	X	X	X	X	X	X	X	1
Boron Trioxide	X	X	X	X	X	X	X	X	X	X	X	X	1

Brake Fluid DOT3 (Glycol Type)	3	1	2	1	3	2	X	2	4	4	4	2	1
Bray GG-130	2	4	4	4	4	4	2	4	1	4	2	2	1
Brayco 719-R (VV-H-910)	3	1	2	X	2	2	4	2	4	4	2	2	1
Brayco 885 (MIL-L-6085A)	2	4	4	4	4	4	2	4	1	1	2	2	1
Brayco 910	2	1	2	2	4	1	3	1	4	3	4	2	1
Bret 710	2	1	2	2	4	1	3	1	4	3	4	2	1
Brine	1	1	X	X	X	X	X	X	1	X	X	X	1
Brine (Seawater)	1	3	4	X	X	X	X	X	1	X	X	1	1
Brom - 113	3	4	4	4	4	4	X	4	X	X	X	3	X
Brom - 114	2	4	2	4	4	4	X	2	2	X	X	3	1
Bromic Acid	3	1	1	1	2	1	4	1	3	4	1	X	1
Bromine	4	4	4	4	4	4	4	4	1	4	2	2	1
Bromine Pentafluoride	4	4	4	4	4	4	4	4	4	4	4	3	2
Bromine Trifluoride	4	4	4	4	4	4	4	4	4	4	4	3	2
Bromine Water	4	2	4	4	4	4	4	1	1	4	2	3	1
Bromobenzene	4	4	4	4	4	4	4	4	1	4	1	2	1
Bromobenzene Cyanide	3	1	1	1	2	1	4	1	3	4	1	X	1
Bromochlorotrifluoroethane (Halothane)	4	4	4	4	4	4	4	4	1	4	2	2	1
Bromoform	2	4	4	4	X	4	4	4	1	3	2	X	1
Bromomethane (Methyl Bromide)	2	4	4	4	X	4	3	4	1	X	1	1	1
Bromotrifluoroethylene (BFE)	X	X	X	X	X	X	X	X	X	X	X	X	1
Bromotrifluoromethane (F-13B1)	X	X	X	X	X	X	X	X	X	X	X	X	2
Brucine Sulfate	3	1	1	1	2	1	4	1	3	4	1	X	1
Buffered Oxide Etchants	X	X	X	X	X	X	X	X	X	X	X	X	1
Bunker Oil	1	4	4	4	2	4	1	4	1	2	1	2	1
Bunker’s “C” (Fuel Oil)	1	X	X	X	X	X	X	X	1	X	X	X	1

Butadiene (Monomer)	4	4	4	4	4	4	4	4	1	4	1	2	1
Butane	1	4	1	3	4	4	1	2	1	1	3	2	1
Butane, 2, 2-Dimethyl	1	4	2	3	4	4	1	2	1	4	3	2	1
Butane, 2, 3-Dimethyl	1	4	2	3	4	4	1	2	1	4	3	2	1
Butanedial	3	1	1	1	2	1	4	1	3	4	1	X	1
Butanol (Butyl Alcohol)	1	2	1	1	2	2	4	1	1	4	1	1	1
Butene 2-Ethyl (1-Butene 2-Ethyl)	1	4	4	4	4	4	1	4	1	4	3	1	1
Butter-Animal Fat	1	1	2	4	2	2	1	2	1	1	1	1	1
Butyl Acetate or n-Butyl Acetate	4	2	4	4	X	4	4	4	4	2	4	4	1
Butyl Acetyl Ricinoleate	2	1	2	4	X	1	X	2	1	4	2	1	1
Butyl Acrylate	4	1	4	4	2	4	4	4	4	X	4	4	1
Butyl Alcohol	1	2	1	1	2	2	4	1	1	4	1	1	1
Butyl Alcohol (Secondary)	2	2	2	2	2	2	4	2	1	4	2	1	1
Butyl Alcohol (Tertiary)	2	2	2	2	2	2	4	2	1	4	2	1	1
Butyl Amine or N-Butyl Amine	1	3	4	4	4	4	4	4	4	4	4	3	1
Butyl Benzoate	3	1	1	1	2	1	4	1	3	4	1	X	1
Butyl Benzoate or n-Butyl Benzoate	4	1	2	4	X	4	X	1	1	1	X	4	1
Butyl Benzolate	X	X	X	X	X	X	X	X	X	X	X	X	1
Butyl Butyrate or n-Butyl Butyrate	4	1	4	4	X	4	X	1	1	1	X	4	1
Butyl Carbitol	4	1	3	4	4	1	4	2	3	X	4	2	1
Butyl Cellosolve	3	2	3	4	X	2	4	4	4	4	4	2	1
Butyl Cellosolve Acetate	3	1	1	1	2	1	4	1	3	4	1	X	1
Butyl Cellosolve Adipate	4	2	4	4	2	2	4	4	2	4	2	2	1
Butyl Chloride	1	4	2	4	2	4	1	2	1	1	1	X	1
Butyl Ether or n-Butyl Ether	3	3	4	4	X	4	3	3	4	3	4	4	1
Butyl Glycolate	3	1	1	1	2	1	4	1	3	4	1	X	1

Butyl Lactate	3	1	1	1	2	1	4	1	3	4	1	X	1
Butyl Laurate	3	1	1	1	2	1	4	1	3	4	1	X	1
Butyl Mercaptan (Tertiary)	4	4	4	4	X	4	4	X	1	4	4	4	1
Butyl Methacrylate	3	1	1	1	2	1	4	1	3	4	1	X	1
Butyl Oleate	4	2	4	4	X	2	X	4	1	X	2	2	1
Butyl Oxalate	3	1	1	1	2	1	4	1	3	4	1	X	1
Butyl Stearate	2	4	4	4	X	4	X	4	1	X	2	2	1
Butylbenzoic Acid	2	4	4	4	X	4	4	4	1	3	2	X	1
Butylene	2	4	3	4	4	4	4	4	1	4	2	2	1
Butyraldehyde	4	2	4	4	4	2	4	4	4	4	4	2	1
Butyric Acid	4	2	4	4	X	2	4	4	2	X	X	1	1
Butyric Anhydride	3	1	1	1	2	1	4	1	3	4	1	X	1
Butyrolacetone	3	1	1	1	2	1	4	1	3	4	1	X	1

Curriculum Vitae

PERSONAL INFORMATION

Name: Seçkin

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Education Status : MSc. Student

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EDUCATION INFORMATION

University (Master's Degree)	**İzmir Katip Çelebi University**
	Engineering and Architecture Faculty
01.2013- 04.2017 (predicted)	Materials Sciences and Engineering (English)
University (Bachelor's Degree)	**Pamukkale University-** (Formal Education)
	Engineering Faculty
09.2008- 06.2012	Mechanical Engineering (English)
High School	**Konak 50. Yıl Lisesi**
06.2007	

WORK EXPERIENCE

- **R&D Executive** 01.2017- … İzmir

  Kastaş Sızdırmazlık Teknolojileri A.Ş.
- **R&D Engineer** 07.2012- 01.2017 (5 years) İzmir

  Kastaş Sızdırmazlık Teknolojileri A.Ş.
- **Internship** 01.2010 - 08.2010 (7 month) Denizli

  Yanmaks Mühendislik Taahhüt San. Tic. A.Ş.
- **Internship** 07.2011 - 08.2011 (1.5 months) İzmir

  Lupamat Makina Sanayi A.Ş.

PUBLICATIONS/PAPERS

- Semiz, S., Devlen, O. "Maden Makinalarında Kullanılan Sızdırmazlık Elemanları ve Yanmaz Hidrolik Akışkanlara Uyumluluk", Oct 2014

KEY TECHNICAL SKILLS

- **Foreign Languages:** English (Advanced)
- **Computer Skills:** Microsoft Office, MATLAB, Autocad, Solidworks, Catia.

ADD. INFORMATIONS

Interests: Dance, Photography, Music, Travelling.

Smoking: Not smoking

PERSONAL TRAITS

Leadership, Good at interpersonal skills and team player, Successful at planning and take action dutifully, Ability of adaptability to change, Goal-oriented and aim for achievement, Energetic and empathic

REFERENCES

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