

## SOFT PVC COMPOUNDING EXTRUDER DESIGN

Beyza AVCI<sup>1</sup>, Ibrahim Savas DALMIS<sup>2</sup>, Serdar Osman YILMAZ<sup>2</sup>

<sup>1</sup> DOMEKS Machinery Ltd. Design Center, Türkiye

<sup>2</sup> Tekirdag Namik Kemal University, Corlu Engineering Faculty, Mechanical Engineering Department, Türkiye

### Abstract

Polyvinyl chloride (PVC) is one of the most preferred thermoplastics in the world due to its compatibility with various additives. PVC products are examined in two groups soft and rigid. Sheath, insulation, and filling materials used in electrical cables are some of the common usage areas of soft PVC. In this study, a soft PVC compound extruder machine was designed and manufactured. The system consists of 6 components: powder feeding system, main rotor, discharge transfer screw system, pelletizer, pellet cooling(cooler) unit and main control panel (HMI). In the designed and produced machine, the temperature values can be entered into the HMI panel according to the desired formulation, and the temperatures of the desired sections can be controlled during the compound production using thermocouples. Heating is brought to the desired level using PID control with resistances, cooling with fans in the main screw area and water in the transfer area. During the compound production process, many values such as temperature and pressure values can be controlled from the material feeding section to the pelletizer section. The density of the soft PVC compound produced was measured as 1.475 gr/cm<sup>3</sup>. The test sample was produced from PVC compound, which was produced via the compounder designed and manufactured in this study, with a laboratory-type extruder. Tensile and elongation tests were carried out according to the ISO 527-2 test method. As a result of the test, it was observed that produced soft PVC compound extended by 280%. As a result of the experiments, it has been determined that the designed and manufactured compounder machine produces the sheath, insulation and filling materials (Plasticized PVC) used in the electrical cables appropriately.

**Keywords:** PVC, PVC compound, machine design, extruder

### INTRODUCTION

PVC is one of the most used thermoplastics in the world. This product, also named PVC compound and more commonly known as PVC granule, is formed by the polymerization of vinyl chloride. PVC is a white or light yellow powder polymer. The monomer of PVC is obtained from ethylene (43%) and chlorine (57%). Its density varies between 1.32-1.42 g/cm<sup>3</sup> and it is possible to operate up to 60°C. It softens at approximately 80°C [1-3].

Polyvinyl chloride is resistant to burning because it contains halogen. It does not burn when it comes into contact with an open flame [3, 4].

Due to the compatibility of PVC with various additives, it is one of the most preferred thermoplastics in the world [2]. PVC can be either hard (rigid) or soft depending on the amount of chemicals added to soften it. Rigid PVC is durable and difficult to handle. It

has high resistance to moisture and chemicals and is used in the production of pipes and profiles. Soft PVC becomes flexible with additives added to hard PVC. Soft PVC can be processed easily and has low heat resistance. It is used in vascular access devices, raincoats, shower curtains, and in the production of materials such as films and foils.

Especially adhesion of PVC to metal surfaces is very high when the PVC, which has low heat stability, is heated. Moreover, it has a wide place in cable manufacturing due to its high resistance to weather conditions, easy processing, adhesion to metal surfaces and good electrical properties [1].

Various research has been carried out on the production and usage areas of Soft PVC granule, which is widely used in daily life.

In their study, Otekaya and Otekaya (2019) produced polyvinyl chloride (PVC) / sepiolite composites using an extruder. Two different

sepiolite powders were used in the study. Morphology changes, chemical behavior and mechanical properties of powders and composites were investigated [5].

In the study conducted by Donduren and Karacasulu (2015), PVC and PC (Polycarbonate) polymers, were injected into plastic injection molds made of AISI 420F stainless plastic mold tool steel, AISI P20 plastic mold tool steel, AISI H11 hot work tool steel and AISI Ç1040 carbon steel. Hardness, density, tensile strength and inorganic filler percentage (ash) tests were carried out on the obtained products. In the study, the most suitable mold steel for the process was determined by comparing the results [6].

Kavlak (2019) aimed to obtain new-generation plastic stabilizers and plastic additives with high UV and thermal resistance, suitable for use in the production of profile paste with transition metal complexes of borate, barbiturate and stearate ligands. The structural properties of the complexes were investigated by various methods. The complexes obtained as a result of the structural analysis of the synthesized complexes were plasticized by the gelation method. PVC paste, which is formed from new-generation thermal stabilizers, has been tested with the thermostatic analysis method defined in the ISO 182-2 standard [7].

In the study conducted by Işık (2019), the effect of the amount of calcite filler contained in the PVC profile compound on the thermal and mechanical properties of the profile was studied. It is predicted that the cost of the compound will decrease with the increase in the amount of calcite filling. Despite this advantage, the negative and positive effects of the increase in the amount of filling on the thermal and mechanical properties of the profile were investigated [8].

In the study conducted by Karamert (2021), the experimental design was used to formulate the cheapest cost PVC granule production, which meets the necessary conditions within the scope of the HAR standard of PVC material. By choosing the most produced cable type, the experimental design method was used on the PVC granule formula used in the production of the H05VK cable. The tests are

applied to the cable after production. After introducing the types of raw materials used in the production of PVC material, PVC granule and cable production processes are explained. The current product costs and test results were compared with the product cost and test results after the experimental design study [9].

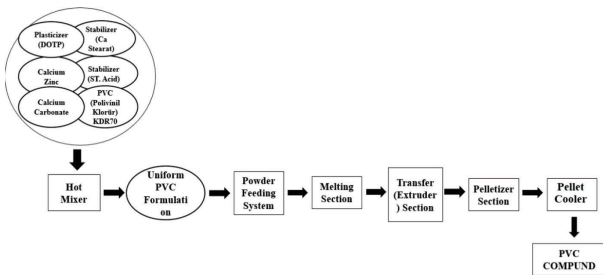
In his study, Polat (2019) determined VCM and PVC production stages, processing techniques, determination of the damage of additives, recycling stages and occupational health and safety risks in this process. In addition, protective and preventive measures to be taken against the identified risks were investigated, the relevant legislation was examined and the necessary measures in terms of occupational health and safety were put forward. The current risks identified in a sector that manufactures plastic products in the province of Uşak were evaluated [10].

As a result of the research, it is seen that PVC is accepted as one of the most important polymers with its production among thermoplastics [11]. Therefore, the demand for PVC compounds continues to increase. To reduce energy consumption, investment and personnel costs, it is much more economical to use a high-capacity machine instead of using more than one machine, in a market where competition is increasing day by day.

In the literature survey, it has been seen that the intensity of academic studies on PVC compound production and material properties is enormous. In this study, a soft PVC granule production machine was designed and produced to increase the industrial production capacity of PVC compound production.

## **MATERIAL AND METHOD**

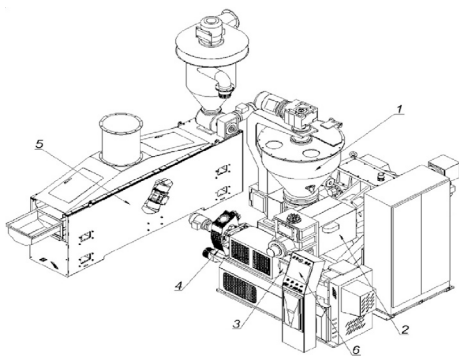
In this study, a high-capacity soft PVC compound production machine was designed. The PVC compound production flow chart is presented in Fig. 1. Developed PVC granule production machine is designed to turn mixtures, containing 20 units to 100 units of Plasticsols (such as DOP or DIDP) and 0 units to 400 units of filler material (Calcite) in 100 units of PVC premixed in a mixer, into the granular compound. It has a production capacity of 500-1000 kg/hour depending on the formulation of the material.



**Fig. 1. PVC Compound Production Chart**

### PVC Manufacturing Machine Components

The position and general components of the PVC production machine, which was designed and produced in the study, on the production line are presented in Fig 2.



**Fig. 2. System General View 1. Powder Feeding System 2. Main Rotor 3. Transfer Screw System 4. Pelletizer 5. Pellet Cooler Unit 6. Main Control Panel**

### Powder Feeding System

The powdered PVC powder, whose pre-mixing process has been completed in the mixer, is loaded into the feeding hopper. The capacity of this hopper is approximately 350 liters. The PVC mixture inside the hopper is transferred to the main rotor using a speed-adjustable transport screw. The amount of PVC mixture in the powder hopper is controlled by a level sensor.

### Main Rotor

It is the section where the powdered material is kneaded and gelled under heat and pressure, so the plasticization process is made. The structure of the rotor(screw) and the outer barrel is conical.

The gap between the barrel and the rotor can be adjusted by moving the position of the rotor inside the barrel back and forth. 12 cartridge resistances with a total power of 10 kW mounted inside the barrel are used to heat the barrel. The conical rotor rotates at a

constant speed and is driven by a 75 kW A.C motor and gearbox. At the output of the rotor(screw), the PVC mixture takes the form of "sausage" in dough consistency and is transferred to the extruder (transfer) screw.

The gases created by the water vapor, mostly caused by the moisture in the material, are released from the PVC mixture that gels on the rotor under heat and pressure. While the PVC mixture, which becomes gelatinous and pastes at the exit of the rotor, is transferred to the transfer screw, the gas released is sucked out by a vacuum circuit.

### Transfer Screw System

PVC mixture coming from the rotor is conveyed to the die plate to be cut to the desired length using an extruder screw. Outside the extruder screw, there is the barrel and resistances for heating it. For cooling, there are copper pipes wrapped around the fan and the barrel. The extruder screw is driven by a 22 kW A.C motor and gearbox.

### Pelletizer

It is the part that cuts the pulpy PVC mixture coming from the transfer screw into granules. It consists of 2 rotating blades working with a forehead-cutting system. The rotation of the rotating blades can be increased or decreased by using the "Cutting +, Cutting -" buttons on the main control panel, depending on the desired grain size. The cutter blades are made of 2 pieces of 0.5 mm spring steel. For the cutting process to be smooth, the cutter spring steels should be operated by pressing the Clamping plate approximately 6-7 mm. If the aspect of the cutting spring steels is low, the cut grains may stick together or if the pressure is too high, it may damage the clamping plate.

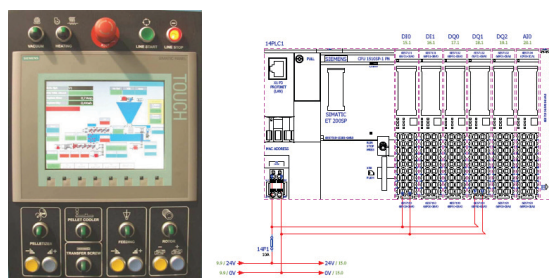
### Pellet Cooler Unit

The hot shear pellets are conveyed to the granule cooling unit by a vacuum fan and a stainless steel flexible hose. In this unit, the pellets are quickly cooled to acceptable pellet temperature by the large cooling fan on the chassis of the GSS1000 and transferred to the outlet due to the vibrating plate of the unit.

### Main Control Panel

The developed PVC compounding machine is controlled by PLC with a touch operator panel (HMI). Errors that occur during the operation of the line are transferred to this

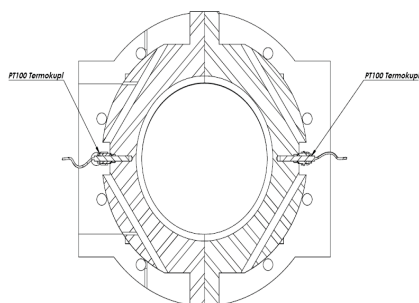
screen (Fig. 3). Siemens S7 CPU 1510SP-1 PN and 6ES7 510-1DJ01-0AB0 brand PLC are used in the control unit of the machine. The PLC program is made in Siemens Tia Portal V17.



**Fig. 3.** Main Control Panel and PLC plan of the system

## RESULT AND DISCUSSION

In the designed machine, the components in the PVC formulation are first transferred to the mixer section. Uniform PVC formulation is obtained by mixing the components transferred to the mixer section. The obtained raw material is transported to the powder-feeding hopper with the help of a screw. Before the machine is started, the heat values of the machine must be adjusted according to the formulation. The desired temperature values are entered on the HMI (Human Machine Interface) panel and the current temperature information is continuously checked with thermocouples (Fig. 4).



**Fig. 4.** Thermocouples

Heating is adjusted to the desired level using PID control with resistances, cooling with fans in the main screw area, and water in the transfer area. When the temperature of the machine reaches the desired level, the main screw motor can be started and the material in the hopper can be fed to the machine. When the material level sensor in the hopper detects that there is no material in the hopper, the material is fed to the hopper with the help of a helix. The main screw, powder feeding, transfer and blade motors in the machine are controlled by drivers. Desired speed

information is entered from the HMI panel and transmitted to the drivers via PLC.

The clearance of the conical screw, which is mechanically connected to the main screw motor, must also be regulated by the operator. On the side of the cone adjustment motor gap behind the main screw, the main screw can be moved back and forth to increase or decrease the clearance distance. This distance varies according to the desired material. The clearance distance control of the main screw is provided by contactors. If the cone adjustment motor moves more than it should, it may cause mechanical problems. Therefore, the limit controls of the motor are provided by inductive sensors.

The material reaching the transfer screw is passed through heaters and coolers, pushed to the die plate and granulated with the help of a blade. The size of the material is adjusted according to the speed of the blade. If the material is longer than it should be, the speed of the blade can be increased and the size of the material can be shortened.

The granulated material is taken with the help of a vacuum, provided by motors, and transferred to the cooler section. The granules coming to the cooler section, which reaches the desired size, are separated with the help of vibration. Vibration in the cooler section is provided by contactors. The granules that reach the desired size are filled into sacks then packed and made ready for use.

The motor powers or resistance powers of the designed and manufactured machine parts are given in Table 1.

**Table 1.** System Motor-Resistance Powers

Machine Parts	Motor/Resistance Powers
Powder Feeding	7,5 kW
Main Shaft	75 kW
Main Shaft Heater 1-2	3x630 W
Transfer Shaft	22 kW
Transfer Shaft Heater 1-2	3500 W
Cone Adjustment Motor	1,1 kW
Vibration Motor	0,18 kW
Pelletizer	1,1 kW
Blade Heater	4x500 W
Cooler Section	<b>Motor/Resistance Powers</b>
Vacuum Motor	11 kW
Cooling Motor 1-2	0,37 kW
Flap Motor	2,2 kW
Vibration Motor 1-2	0.37 kW

The units of the PVC extruder machine designed and produced are shown in Fig. 5.

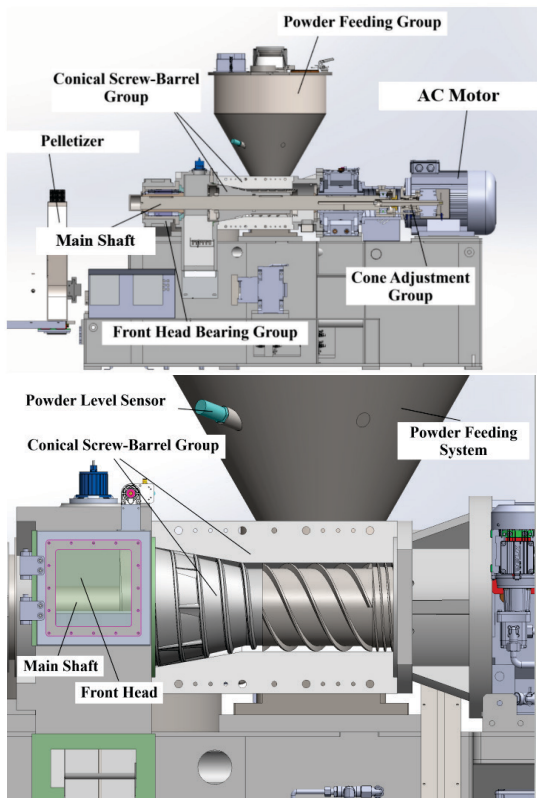


Fig. 5. PVC production machine parts

In this study, the performance of the designed and manufactured machine has been tested. As a result of the experiments, it has been determined that the machine produces the sheath, insulation and filling materials (Plasticized PVC) used in the electrical cables appropriately.

In the experiments carried out on the designed and manufactured machine, the insulation material generally used in electrical cables was examined. The chemical components of this material are listed in Table 2.

Table 2. Chemical composition of the material

Component Name	Unit Used
PVC (Polyvinylchloride)	100 unit
KDR70	
Plasticizer (DOTP)	55 unit
Calcium Carbonate	70 unit
calcium Zinc	5 unit
Stabilizer-1 (Ca Stearat)	0,1 unit
Stabilizer-2 (St. Acid)	0,8 unit

The operating temperatures and pressures of the machine are given in Table 3 for the material whose chemical components are specified. Temperature zones of the machine shown in Fig.6.

Table 3. Temperatures and pressures of machine sections

Machine Parts	Temperature/ Pressure
Melting temperature (where mixing occurs)	150-170°C
Transfer section temperature	130-150°C
Pelletizer temperature	130-140°C
Pelletizer pressure	50-70 bar

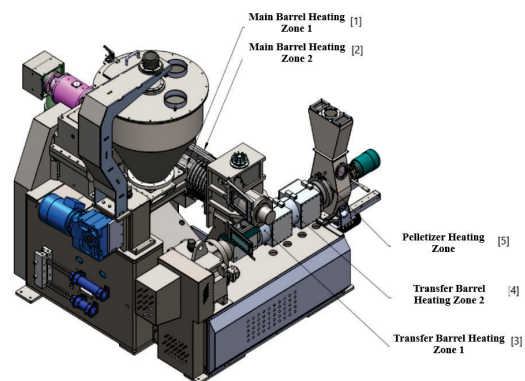
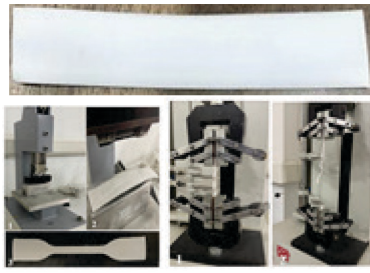


Fig. 6. Temperature Zone

When the material, whose chemical composition is given in Table 2, is operated at the specified temperatures and pressures, a production capacity of approximately 800 kg/h is reached. Approximately 60 kW of electricity is consumed to obtain the product with the desired capacity.

Product capacity, temperatures and pressures vary according to the density of the material used. A laboratory type extruder is used to determine the homogeneity of the produced product.

The homogeneity of the product is determined by taking a test sample from the laboratory-type extruder, whether it is dispersed properly or not, and whether the surface is visually smooth. It can be applied in various tests (tensile test, density measurement, aging in water, heat treatment, etc.) to the materials produced according to the desired product properties. A tensile test sample is taken from the strip sample and sampling steps are shown in Fig.7.



**Fig. 7.** Strip sampling and tensile testing of samples

Density, strength, tenacity and elongation, hardness and moisture ratio tests were applied to the PVC compound produced under the working conditions specified in Table 4. In these measurements, Radwag MAC 50 moisture analyzer, tensile strength tester – Devotrans and Precisa XB 220A density meter devices were used.

**Table 4.** Work conditions

Zone	Temperature °C
1	140
2	150
3	150
4	160
5	160
Frequency (Hertz)	35
Flow (A)(Current)	17
Melt Material Temperature °C	180

As a result of the measurements;

- Produced PVC compound under the working conditions specified in Table 4., is in the appearance of brown granules.
- The density value was measured as 1,475 gr/cm<sup>3</sup> according to ISO 1183 A test method.
- Strength value of 17 N/mm<sup>2</sup> was measured according to ISO 527-2 test method.
- A test sample was produced from the produced PVC compound with a laboratory-type extruder. Tensile and elongation tests were carried out on the produced sample according to the ISO 527-2 test method. As a result of the test, the elongation was measured to be 280%.
- Hardness value 48 Shore-D was measured according to ISO 868 test method.
- The humidity rate was measured as 0.01% according to the ISO 787/2 test method.

## CONCLUSION

With this study, a high-capacity soft PVC production machine was designed. At the end of the design, various analyzes were applied to the soft PVC compound produced in the machine. It has been observed that the values obtained as a result of the tests are meeting the standards. As a result of the experiments, the machine has been determined that it has a production capacity of 500-1000 kg/hour depending on the formulation of the material. In future research, improvements in machine performance will be possible with the changes to be made in the conical screw design. With the new screw designs, it will be possible to use the machine for different products.

## ACKNOWLEDGMENT

This study was supported by DOMEKS Machinery Ltd Design Center.

## REFERENCE

- [1] Aydin, H. PVC Production and Additives. Graduation Thesis, Osmangazi University Faculty of Arts and Sciences, Eskişehir, 2004.
- [2] Kiralp, S., Ozkoc G., Erdogan, S., Camurlu, P., Dogan, M. ve Baydemir, T. Modern Age Material Plastics. METU Science and Society Books Series, METU Publishing 2007.
- [3] Hazer, B. Polymer Technology. K.T.U. Printing house, Trabzon, 1993.
- [4] Rotheiser, J. Joining of Plastics. Hanser Publishers, Munich, 1999.
- [5] Braun D. Poly (vinyl chloride) on the way from the 19th century to the 21st century. Deutsches Kunststoff-Institut, Schlossgartenstrasse 6, Darmstadt, Germany, June, 30,06,2003.
- [6] Donduren, H. V., Karacasulu, S. S. The Most Appropriate Mold Steel Selection for PVC (Polyvinyl Chloride) and PC (Polycarbonate) in Plastic Injection Molds. Süleyman Demirel University, Journal of the Institute of Science, July,31,7,2015.
- [7] Kavlak, I. Investigation of New Generation Stabilizers and Additives with High Thermal and UV Resistance Suitable for Use in PVC Profile Compound Production. Ph.D. Thesis, Eskişehir Osmangazi University, Institute of Science and Technology, 2019.
- [8] Isik, G. Effect of Pvc Profile Compound Fill Amount on Mechanical and Thermal Properties

- in Extrusion Process. Master Thesis, Ege University, Department of Chemical Engineering, Izmir, 2019.
- [9] Karamert, Ç. Using Fractional Factorial Experiment Design in PVC Production Process. Master Thesis, Ondokuz Mayıs University, Graduate School of Education, Department of Statistics, Samsun, 2021.
- [10] Polat, Y. E. Potential Risks and Occupational Health and Safety Practices in the Polyvinyl Chloride (Pvc) Industry. Master Thesis, Uşak University, Institute of Science and Technology, Usak, 2019.
- [11] Otekaya, H. C., Otekaya, M. O. Chemical and Mechanical Properties Analysis of Extruded Polyvinyl Chloride (PVC)/Sepiolite Composite. Sakarya University Journal of Science, February, 14,02,2019.