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DESIGN AND DEVELOPMENT OF A MULTI-PURPOSE COMPOUND PRODUCTION MACHINE WITH INTERLOCKING AND CO-ROTATING REVERSE CONICAL SCREWS

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ABSTRACT

Polymer-based compounds such as PVC, HFFR, PE, PP, and engineering polymers are widely used in the cable industry as sheath, insulation, and filling materials due to their mechanical, electrical, and environmental advantages. However, in their processing, challenges such as mixing homogeneity and production efficiency remain significant limitations in conventional systems. Inadequate mixing or uneven dispersion of additives not only reduces production efficiency but also directly affects the mechanical properties of the final product such as tensile strength, elongation value and flexibility. In this study, a multi-purpose compound production machine equipped with intermeshing and co-rotating counter-conical screws was designed, manufactured, and tested. The system consists of six main components: ribbon mixer, feeding unit, twin conical screws, transfer screw, granule cutting and cooling unit, and a PLC-based main control panel (HMI). The homogeneity and desired dispersion of the compound were confirmed by microscopic examinations, SEM analysis, and mapping analysis. Mechanical tests demonstrated that the compound had a tensile strength of 14.72 N/mm² and an elongation value of 173%, along with hardness, density, and moisture measurements, all meeting industrial standards. The developed machine provides significant advantages over conventional systems in terms of mixture homogeneity and production efficiency.

1. INTRODUCTION

The rapidly increasing global energy demand has led to a rise in the need for energy transmission and distribution, which in turn directly affects the use of cables. Power cables are widely utilized in every aspect of daily life homes, workplaces, schools, dormitories, and hospitals and have become an indispensable component of modern society. However, this widespread use also brings forth various safety and performance requirements [1-2].

Cable insulation and sheathing materials are generally polymer-based. PVC, HFFR compounds, PE, PP, PS, PMMA, PC, PA, and bio-based polymers are among the most widely used materials in this field. Each polymer group offers different advantages and limitations in terms of cost, processability, electrical performance, environmental impact, and fire safety. For instance, PVC is one of the most preferred thermoplastics in the cable industry due to its high compatibility with additives, ease of processing, and suitable electrical properties [3-5]. HFFR systems, on the other hand, have been developed in line with health and environmental concerns, and provide significant benefits with their halogen-free structure and low smoke density [6]. Moreover, PE and PP are commonly preferred for their cost-effectiveness and mechanical durability, while engineering polymers such as PC and PA are used in specialized high-performance applications. This diversity highlights the industry's need for multiple polymer solutions rather than a single universal material.

The performance of polymer-based materials is influenced not only by their chemical composition but also by the characteristics of the production processes. Currently, compound production is primarily carried out on extrusion-based lines, where raw material quality, screw design, temperature profile, shear rate, pressure, and feeding strategy are critical factors determining the mechanical and chemical properties of the final product. However, current systems face challenges such as high energy consumption, limited process flexibility, reduced production efficiency, and difficulties in processing different polymer systems on the same line. Additionally, the inability to maintain stable process conditions often leads to fluctuations in product quality. For this reason, the industry's pressing need is the development of compact and flexible compounding lines that enable the safe, reproducible, and cost-efficient processing of diverse polymers.

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In the literature, numerous studies have been carried out on different compounds and their processing technologies, mainly focusing on material properties and manufacturing methods. Avcı et al. (2022) designed and manufactured a special extruder for the production of soft PVC compounds, achieving effective temperature control through a PID system combined with air-and water-cooling mechanisms. Their results showed that the produced compound had a density of 1.475 g/cm³ and exhibited 280% elongation under ISO 527-2 testing, indicating its suitability for insulation, sheathing, and filler applications in electrical cables [5]. Similarly, Öztürk and Özbaran (2021) developed a Twin and Conical Screw Extruder to improve mixing homogeneity and process efficiency by enhancing material flow and heat removal within the barrel, thereby maintaining the physical, mechanical, and chemical properties of the compound [7]. Hyvärinen et al. (2020) reviewed modeling approaches for polymer extrusion, emphasizing that conventional methods often fail for multiphase composites and highlighting the growing importance of CFD/FEM-based tools [8]. Doruk et al. (2020) investigated mineral fillers in halogen-free flame-retardant (HFFR) cable compounds, demonstrating that ATH and MDH improve flame-retardant performance while also affecting mechanical properties depending on filler content [9]. Öteyaka and Öteyaka (2019) studied PVC/sepiolite composites and reported that low sepiolite additions improved tensile strength, while higher loadings induced surface cracks and reduced mechanical performance [10]. Other studies by Öztürk and Özbaran (2010, 2015) and Özbaran (2005) introduced innovative machine designs to improve homogenization, degassing, and process stability in PVC granulation [11–13].

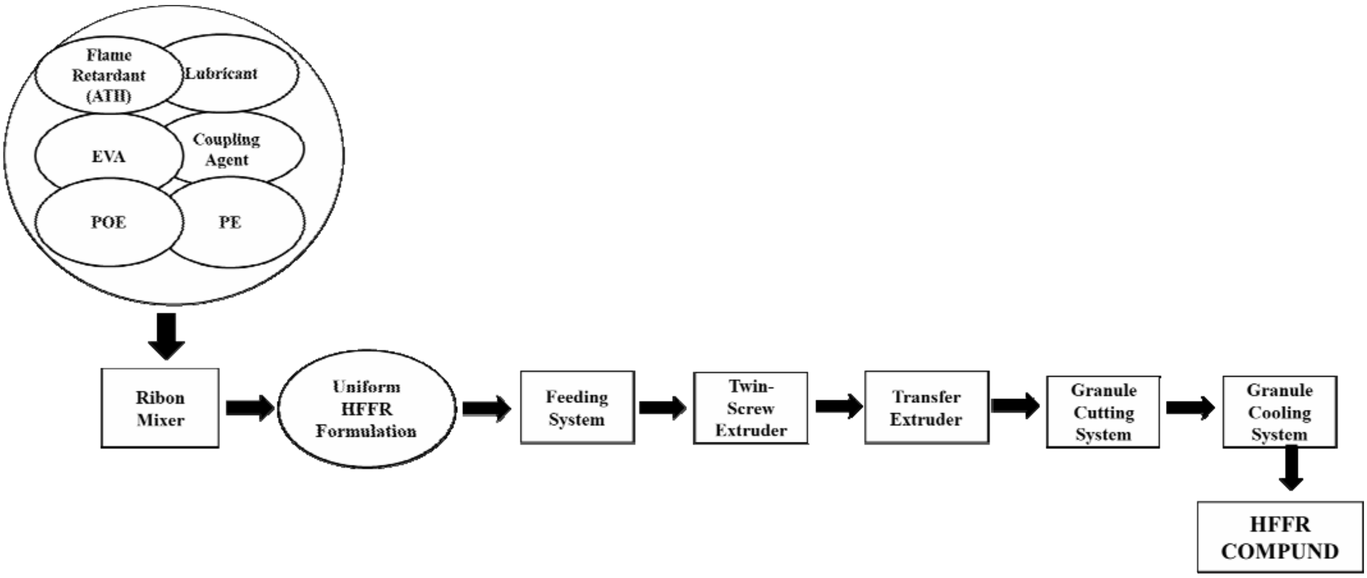

Fig. 1. HFFR Compound Production Chart

2. EXPOSITION

A review of these studies shows that much of the existing research has focused on improving material properties, enhancing flame-retardant performance, and optimizing process parameters. Nevertheless, challenges remain in addressing mixing issues in high-filled and shear-sensitive polymers, as well as in achieving process flexibility within compounding lines. Building upon this background, the present study introduces a compact system featuring co-rotating reverse conical screws, which enhances both dispersive and distributive mixing capability, improves material stabilization, and enables efficient single-point feeding. In this way, a holistic approach is proposed to overcome production-line-related challenges such as investment cost, process efficiency, and mixing homogeneity.

3. MATERIALS AND METHODS

In this study, a multi-purpose compound production machine was designed to ensure the homogeneous mixing of polymers. The developed machine optimizes material flow through the high performance provided by its screw system. This design is equipped with components, each fulfilling different functions. The system operates quickly and efficiently in the production of various types of polymers, offering a wide production capacity. A sample compound production flow diagram is presented in Figure 1.

Manufacturing Machine Components

The position of the compound production machine, which was designed and manufactured in this study, within the production line and its main components are presented in Figure 2.

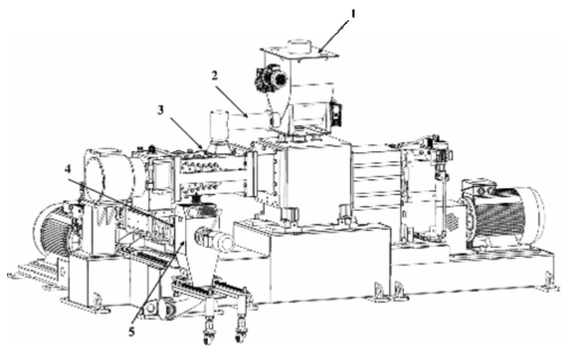

Fig. 2. System General View 1. Ribbon Mixer 2. Feeding Unit 3. Twin Conical Screw 4. Transfer Screw System 5. Granule Cutting System

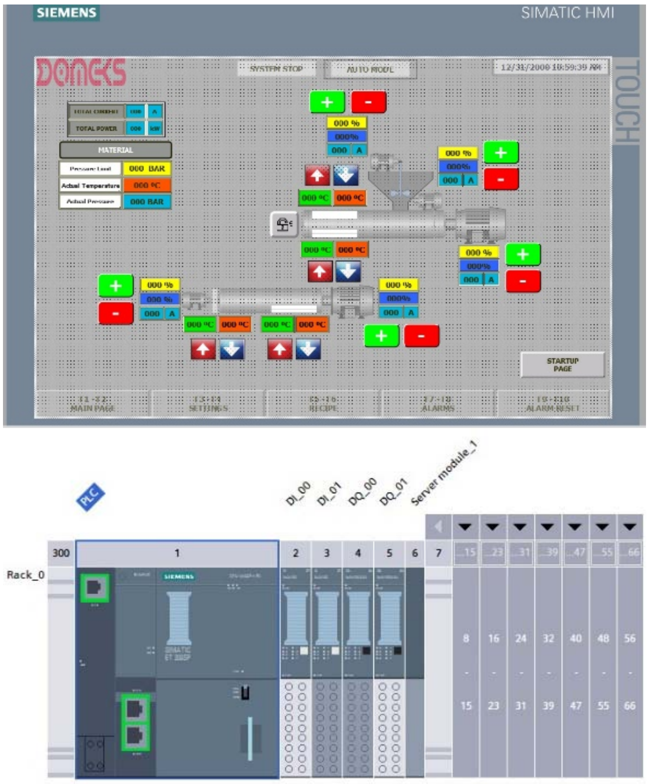

Fig. 3. Main Control Panel and PLC unit

Ribbon Mixer

The pre-formulated raw materials are taken from the dosing system and mixed inside the ribbon mixer. Once the pre-mixing process is completed, the materials are transferred to the feeding unit. The load cells integrated into the ribbon mixer monitor the material level inside the mixer to ensure the continuity of the production process. When the material level decreases, the system triggers the dosing unit to supply new raw materials.

Feeding Unit

The raw materials that have completed the pre-mixing process are loaded into the feeding hopper for production. This hopper has a capacity of approximately 100 liters. The material inside the hopper is transferred to the conical screw section via a speed-controlled conveying screw. The amount of material in the feeding hopper is continuously monitored by a load cell. When the material level drops below a certain threshold, new raw materials are automatically added to the hopper in accordance with the formulation to ensure the continuity of the production process.

Twin Conical Screw

The raw materials transferred from the feeding unit are delivered to the section where they are kneaded and gelled under heat and pressure, undergoing a plasticizing process. The screw guiding the material is conically shaped, and by adjusting the rotational speed of the main screw, the gelling process of the material is controlled. To heat the barrel, 28 cartridge heaters with a total power of 1500 kW are installed inside. The conical screw rotates at a constant speed and is driven by a 90 kW motor and gearbox. At the outlet of the twin conical screw, the gelled material reaches a dough-like consistency and is directed to the transfer screw.

During the gelling process on the twin conical screw, gases released from the material are typically due to moisture content within the raw material. These gases are extracted by a vacuum system positioned at the outlet, ensuring that the gelled, dough-like material is transferred to the next stage without trapped volatiles.

Transfer Screw

The dough-like raw material mixture exiting the twin conical screw is conveyed toward the compression plate (screen) via the twin conical transfer screw, where it will be cut into the desired size. The outer section of the twin conical transfer screw is equipped with heating elements (resistances) for thermal control, and cooling is achieved using circulating water. The barrel also includes dedicated cooling channels to facilitate water flow. The transfer screw is driven by a 75 kW motor and gearbox.

Granule Cutting System

The dough-like raw material exiting the twin conical transfer screw is directed to the cutting unit to be shaped into granules. This section consists of two rotary blades operating with a face-cutting system. The speed of the rotary blades can be increased or decreased using the 'Cut +' and 'Cut –' buttons on the main control panel, depending on the desired granule size.

The cutting blades are made of spring steel with a diameter of 1.2 mm. To ensure proper cutting, a pressure of approximately 5 mm must be applied against the compression plate during operation. If the pressure of the spring steel blades is insufficient, proper granule formation cannot be achieved, resulting in burrs and adhesion. Conversely, excessive pressure can damage both the compression plate and the cutting blades.

Granule Cooling System

The hot-cut pellets are transported to the granule cooling unit via a vacuum fan and a flexible hose. In this unit, the pellets are rapidly cooled to a target temperature set by the cooling fan. After cooling, they are conveyed to the outlet through a vibrating plate integrated into the unit.

Main Control Panel

The developed compound production machine is operated via PLC control through a touchscreen operator panel (HMI). Any faults or errors that occur during line operation are displayed on this screen (Figure 3). The control unit of the machine is equipped with a Siemens S7 CPU 1510SP-1 PN and a Siemens PLC, and the PLC programming has been carried out using Siemens TIA Portal V18.

4. RESULTS AND DISCUSSION

In the designed machine, a twin conical counter-rotating screw system is used to ensure the homogeneous mixing of polymers and the production of compound material. The material is fed into the machine through a single-point feeding system and progresses between counter-rotating conical screws turning in the same direction. Thanks to their dispersive and distributive mixing capabilities, these screws enable the homogeneous blending of high-filled and shear-sensitive materials.

While the material is transported in a controlled manner through the screw conveying section, the mixing process is completed in the compression zone under the influence of pressure and temperature. By increasing the homogeneity of the mixture, a stable compound is achieved. The material transported to the discharge section through the screw pockets is directed to the granule screen via the transfer screw and then cut into the desired sizes in the granule cutting unit to form the final product.

This entire process is controlled by a PLC-based automation system. The necessary drivers, input and output modules, analog modules, and communication network are configured and commissioned for the system. Each module is tested individually to ensure stable system operation and uninterrupted Production.

The motor powers of the designed and manufactured machine are given in Table 1. The units of the multipurpose compound production machine, which is equipped with intermeshing and co-rotating counter-conical screws (shown in Figure 5), are shown in Figure 4. The chemical components of the compound material used in the experiments are presented in Table 2, while the operating temperatures and pressure values for this material are given in Table 3, and the temperature zones are illustrated in Figure 6. The compound production machine developed within the scope of this study provides significant advantages over existing systems in terms of mixture homogeneity, production efficiency, and energy optimization.

Table 1 *System Motor Powers*

Machine Parts	***Motor Powers***
Powder Feeding Unit	*0.75 kW*
Main Shaft	*90 kW*
Main Shaft Heater	*1500*28 Watt*
Transfer Shaft	*75 kW*
Transfer Shaft Heater	*1500*7 Watt*
Mixer Motor	*0.75 kW*
Filter Heater	*1000*2 Watt*
Cutting Motor	*2.2 kW*

Table 2 *Chemical composition of the material*

Component Name	***Unit Used***
LLDPE	*7 Unit*
POE	*11,5 Unit*
EVA	*12 Unit*
ATH	*60 Unit*
ADDITIVE	*9,9 Unit*

Table 3 *Work conditions*

Zone	***Temperature °C***
1	*35-50 °C*
2	*35-50 °C*
3	*170-190 °C*
4	*150-170 °C*
5	*150-170 °C*
Frequency (Hertz)	*35*
Flow (A) (Current)	*17*
Melt Material Temperature °C	*180 °C*

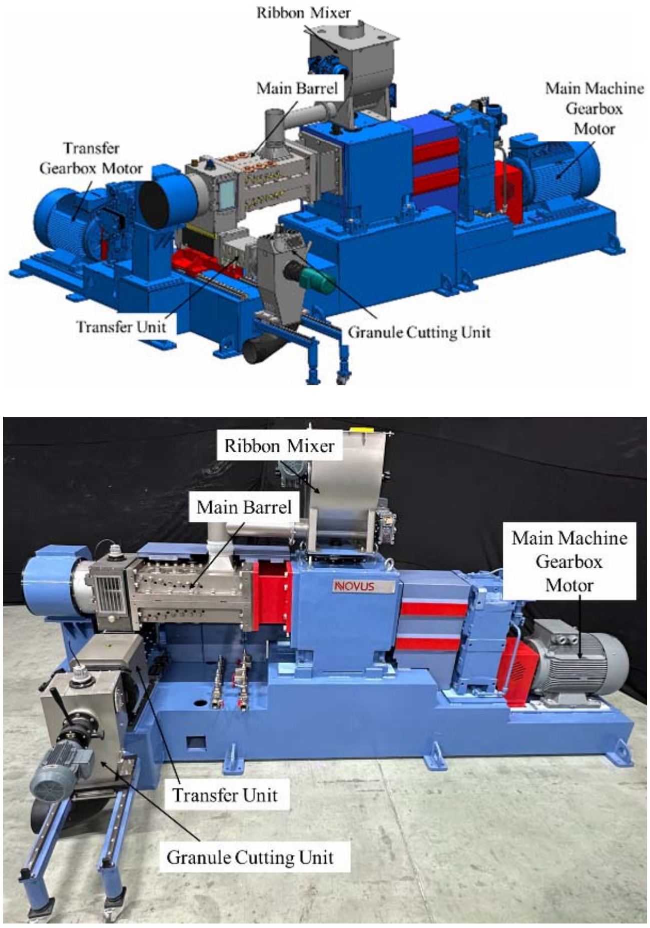

Fig. 4. Compound production machine parts

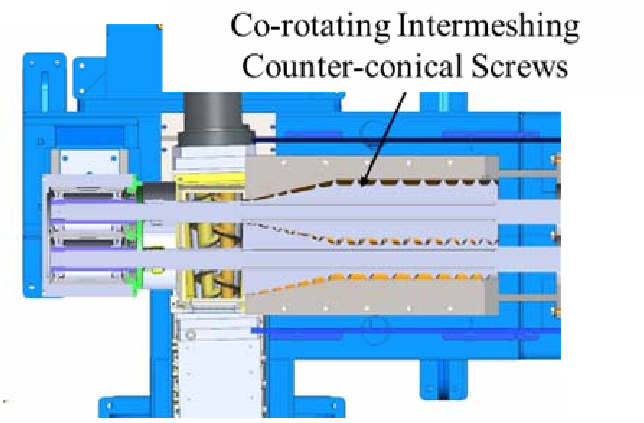

Fig. 5. Co-rotating Intermeshing Counter-conical Screws

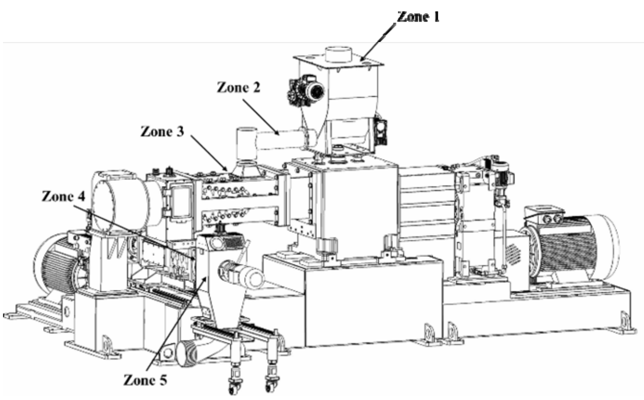

Fig. 6. Temperature Zone

The compound production machine developed within the scope of this study provides significant advantages over existing systems in terms of mixture homogeneity, production efficiency, and energy optimization. The achievement of homogeneity and the desired dispersion was confirmed through microscopic examinations (Fig. 7), SEM analysis (Fig. 8), and mapping analysis (Fig. 9).

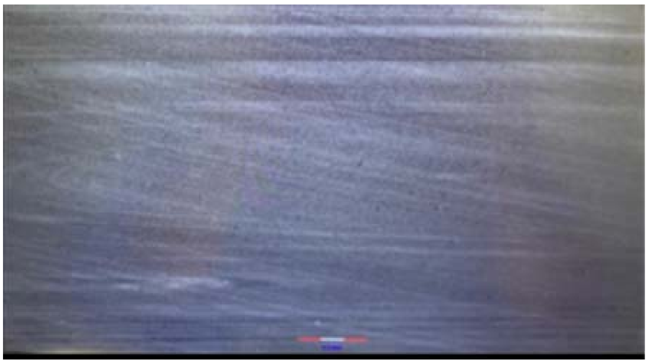

Fig. 7. Microscopic examinations

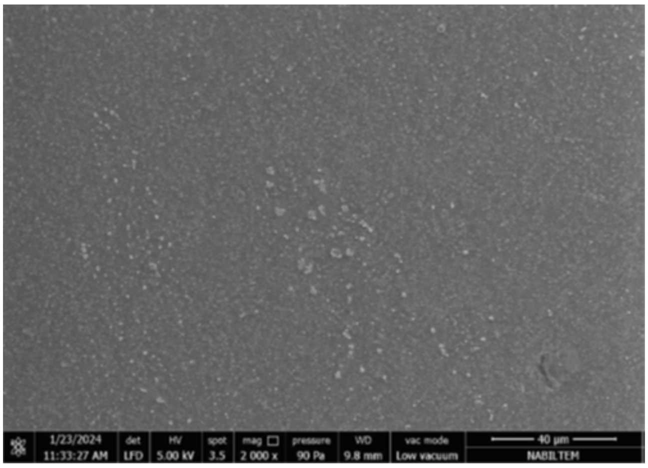

Fig. 8. SEM analysis

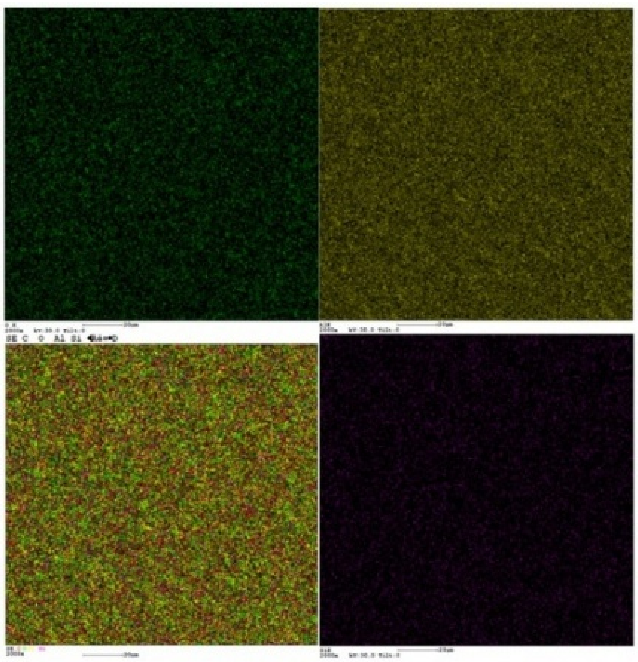

Fig. 9. Mapping analysis

In order to determine the homogeneity of the produced compound, strip samples were taken from a laboratory-scale extruder. These samples were evaluated in terms of their dispersive and distributive mixing characteristics, as well as surface smoothness, through visual inspection.

To verify that the produced material met the required performance properties, various tests were conducted, including tensile testing, density measurement, water aging, and thermal treatment. Tensile test specimens were prepared from the strip samples, and the sampling procedure is illustrated in Figure 10.

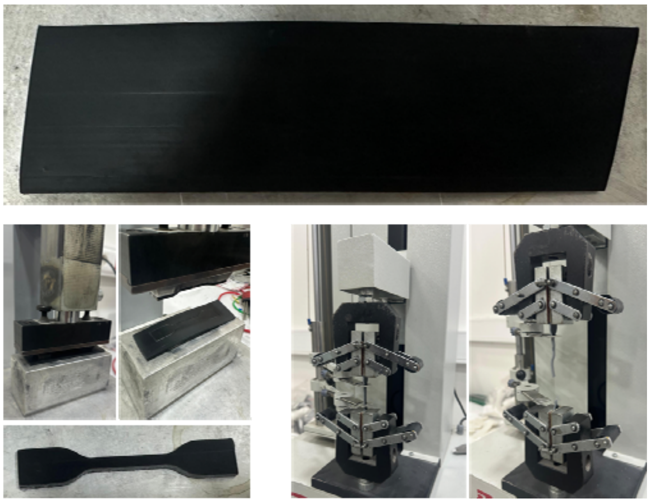

Fig. 10. Strip sampling andtensile testing of samples

Under the operating conditions specified in Table 3, the HFFR sheathing compound was subjected to tests of density, tensile strength, durability, elongation, hardness, and moisture content. The measurements were carried out using a Radwag MAC 50 moisture analyzer, a Devotrans tensile strength testing machine, and a Precisa XB220A density meter.

As a result of the measurements:

• The density value was measured as 1.466 g/cm³ according to the ISO 1183 A test method.

• The tensile strength value was determined to be 14.72 N/mm² according to the ISO 527-2 test method.

• A test specimen was prepared from the produced HFFR compound using a laboratory-type extruder. Tensile and elongation tests were carried out on the prepared specimen in accordance with the ISO 527-2 test method. As a result of the test, the elongation value was measured as 173%.

• Hardness value 52 Shore-D was measured according to ISO 868 test method.

5. CONCLUSION

In this study, a multi-purpose compound production machine equipped with intermeshing and co-rotating counter-conical screws was successfully designed, manufactured, and tested. The developed system demonstrated significant advantages over conventional compounding machines, particularly in terms of mixture homogeneity, production efficiency.

The homogeneity and targeted dispersion of the compound were verified through microscopic examinations, SEM analysis, and mapping analysis. In addition, mechanical and physical property tests including tensile strength, elongation, hardness, density, and moisture content showed that the produced compounds met the required industrial standards.

The findings highlight that the proposed machine provides an effective, flexible, and reliable solution for the processing of high-filled and shear-sensitive materials, enabling stable production and consistent product quality. Future studies will focus on optimizing the conical screw design to further enhance process performance, expand the production capacity range, and adapt the system for different polymer-based compounds.

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