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Recommendations for Mixing Secondary Polymer Waste with Primary Raw Materials and Their Application

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Abstract: This article considers the increasing demand for polymer products, particularly the recycling of secondary polymer waste to produce plasticized products. Taking this into account, an innovative technology for manufacturing products based on local secondary polymer waste has been developed and recommended for practical application.

Keywords: polyvinyl chloride (PVC), polymer composite materials (PCM), tensile strength, flexural strength.

In our country, mixing polymer waste of various chemical compositions and properties with composites to produce plasticized secondary products has become a common practice. However, the mechanism by which the physical-chemical, technological, and operational properties of polymer composite materials are affected during the reprocessing of molten polymer mixtures has been insufficiently studied to date. It is worth noting that great attention is being paid in our republic to the implementation of innovative technologies, the establishment of a scientifically grounded system for managing industrial enterprises, and the development of measures for environmental protection.

In the Action Strategy for the Further Development of the Republic of Uzbekistan, important tasks have been outlined, including "accelerating the production of high-value finished products through deep processing of local raw material resources and modifying product and technology types in terms of quality."

One of the most widely used methods for utilizing secondary polymer waste is mixing shredded secondary polymer waste with primary raw materials. The physical-chemical properties of polymer waste do not significantly differ from those of the original raw material being recycled. Many thermoplastics (**PBPE, LLDPE, PS, PMMA**) retain their properties even after being recycled 2-5 times.

The main challenge in reprocessing mixed polymer waste is the degradation processes that occur within the material. Over time, the structure and composition of polymer materials deteriorate due to prolonged use, causing the additive properties of the components to deviate from standard principles.

For thermoplastics, a general trend is observed: introducing a new polymer into mixed polymer waste improves the properties of the final product. However, the proportions of the new polymer and mixed polymer waste depend on the type of the newly introduced polymer. Based on practical recommendations, the following guidelines have been developed for three types of local raw materials:

- **PBPE:** As the proportion of mixed polymer waste (film material) increases, the viscosity-flow index decreases 2-5 times, the tensile strength drops from 16 MPa to 8 MPa, and the elongation at break is reduced from 600% to 60%.
- **LLDPE:** This material retains its properties relatively well. When up to 20% of mixed polymer waste is added to the primary polymer, certain strength and viscosity properties improve. However, if the proportion of mixed polymer waste increases further, the physical-mechanical and rheological properties of the polymer begin to deteriorate.
- **PP:** Polypropylene is more susceptible to degradation compared to other polyolefins. When 20-50% of primary polymer is added to mixed polymer waste, the viscosity of the melt drops sharply, the viscosity-flow index decreases 5-10 times, and the deformation-strength properties deteriorate. The reprocessing method can also influence the properties of the resulting polymer material. When reprocessing PP and mixed polymer waste using the extrusion method, the optimal ratio is 1:1.
- **PVC:** It is recommended to add up to 50% mixed polymer waste to the primary polymer composition. The properties of the mixture are significantly influenced by technology and grinding quality. The best results in grinding secondary mixed waste are achieved when they are ground into a powder form. Additionally, the properties of PVC and secondary mixed waste are also affected by the addition of lubricants and plasticizers.

Due to thermal motion, plasticizer molecules tend to penetrate between polymer macromolecules. As a result, the flexibility of the polymer structure increases. This, in turn, lowers the softening temperature of the composition, making reprocessing (such as injection molding, extrusion, blow molding, stamping, etc.) easier.

Picture 1. Two-Stage Mixer

Homogeneous industrial waste is usually recycled according to the standard method for PVC. In this case, only the thin surface layer of the polymer waste undergoes deep "aging." To separate metal and mineral components, the induction method used in the flour production industry, which is based on the properties of a magnetic field, can be applied. To separate aluminum foils from thermoplastics, water heated to 95-100°C is used. Containers with unusable labels are proposed to be placed in liquid nitrogen or oxygen with a temperature not exceeding -50°C. As a result, the labels become brittle, lose adhesion, and become easier to crush and separate from similar materials.

The use of a compactor for preparing plastic waste in dry form is considered an energy-efficient method. This method is applied to artificial leather and PVC-based linoleum and includes several technological operations: crushing, fiber separation, plasticization, homogenization, compaction, and granulation; additional components can also be added.

Base fibers are separated three times—after the first knife crushing, after compaction, and after the second knife crushing. After obtaining a moldable mass, the final product is obtained.

PVC is one of the most stable carbon-chain industrial polymers. The degradation reaction of PVC—dehydrochlorination—begins at 100°C, but accelerates significantly at 160°C. Due to thermal oxidation, both crosslinking and degradation processes occur in PVC.

The degradation of PVC begins with the fading of its external color and leads to a deterioration of its physical-mechanical, dielectric, and operational properties. As a result, three-dimensional crosslinking occurs in the polymer structure, forming linear and branched macromolecules, which reduces solubility and worsens its reprocessing properties.

Considering the negative factors mentioned above, it is important to properly assess the issues of recycling polymer materials based on the secondary composition of PE, PP, and PVC and making rational use of waste.

When producing products using extrusion from mixed raw materials, the difference in viscosity between polymers increases the likelihood of defective (reject) products.

The main types of unfilled PVC waste include non-gelatinized plastisol, technological waste, and defective products. In industrial enterprises in our country, methods of reprocessing plastisol waste using pressure molding technologies are actively implemented.

During the cleaning of the dispenser and mixer, the non-gelatinized plastisol was collected in a container and gelatinized, then mixed with technological waste and defective products in rolls. The obtained sheets were ground in a rotor-type crusher. The resulting plastisol crumb was reprocessed using the pressure casting method. By preparing a composition of 10-50 mass parts of plastisol crumb with rubber, rubber mixtures can be obtained. In return, plasticizers can be removed from the formulation.

To utilize the pressure casting method for recycling waste, machines operating on the intrusion principle should be used according to regulations. These machines must have continuously rotating screws that homogenize the waste and ensure the progressive movement of the polymer melt.

In the multi-component casting method for PVC waste, products consist of outer and inner layers made of different materials. The outer layer is a high-quality, stabilized, colored plastic product with an aesthetically pleasing appearance. The inner layer consists of secondary PVC raw material. This method significantly conserves scarce primary raw materials and reduces demand for them by half.

During PVC waste recycling, modification can be carried out by introducing 1-3 mass units of metal-containing thermostabilizers and 10-30 mass units of plasticizers into the initial raw material composition simultaneously with dispersion. This increases the thermal stability of the polymer material by 15-50 minutes, improves its flowability, and simplifies the dispersion process. The obtained secondary PVC materials have high dispersibility and favorable particle surface properties, enhancing the polymer's surface activity. These characteristics facilitate better interaction with other materials, allowing up to 45% of the initial raw materials to be replaced.

Twin-screw extruders can also be effectively used in PVC waste recycling. In these extruders, the material transforms into a homogeneous mixture, and the plasticization process occurs under relatively mild conditions. Polymers undergo efficient plasticization in twin-screw extruders, with minimal instances of burning and degradation during reprocessing. Inside the cylinder, the polymer melt undergoes effective degassing, removing degradation and oxidation products, moisture, and other volatile substances present in the waste.

To recycle polymer composite materials (PCM), including cable insulation waste, thermoplastic coatings based on paper, and others, extrusion and pressing methods can be used. To implement this method, an aggregate consisting of two machines is proposed, each spraying 10 kg. The amount of special additives in the waste composition that do not contain polymers can reach up to 25%, while the copper content can be up to 10%.

Thermoplastic waste polymers can also be processed using the co-extrusion method to produce three-layer products (e.g., films). Additionally, a blow molding method has been proposed. The developed extrusion-blow molding device includes a screw-disk extruder as a melt generator with blowing capability. By extruding and blowing primary and secondary PVC mixtures, butyl, various containers, and other products can be manufactured [2; 24-27].

An example of the calendering method for secondary polymer waste is the process called "Regal." This method involves calendering the material to produce sheets and plates for furniture and packaging production. The advantage of this method is that by adjusting the gap between the calender rolls, the material's flow and dispersion characteristics can be improved. During recycling, the material undergoes effective plasticization and homogenization, ensuring high strength characteristics in the final product. This method is economically feasible for plasticized soft PVC thermoplastics and operates at relatively low temperatures [3; 16-20].

Another traditional recycling method for secondary waste is pressing, with the most common variation currently known as the "Regal-Converter" process. In this method, finely ground polymer waste is transported on a conveyor belt into a furnace, where it is melted. The plasticized polymer mass is then pressed. This proposed method allows recycling of plastic mixtures containing more than 50% foreign substances [4; 60-65].

In addition, there are continuous recycling methods for synthetic carpet waste. The process involves feeding shredded waste into a mixer, where 10% binding material, dye, and filler are added. Due to the porosity of the resulting plates, they provide excellent heat and sound insulation. These plates are widely used as structural elements in the automotive industry and in furniture manufacturing.

In the United States, heavy-weight plates are produced using the pressing method. Additionally, another technological approach based on foaming in molds is also applied. The developed variations differ in terms of adding foaming agents to the secondary raw material composition and applying heat. Foaming agents can be introduced into a closed mixer or an extruder.

A drawback of this method is that when polymer waste is pressed, the mixture components do not blend well with each other, leading to a decrease in the mechanical properties of the final material. Currently, extensive research is being conducted on the regeneration of PVC plastic waste [134; 24-28].