DOI 10.52209/2706-977X_2024_4_71 **IRSTI 81.09.01** **UDC 622.2**

Influence of Processing Conditions on the Particle Size Distribution of Recycled Cable Insulation

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Abstract. The particle size during the shredding process of electrical cables primarily affects the efficiency of copper separation from plastic and the energy consumption of the processes. This article aims to determine the particle fractions of plastic materials (cable sheathing) after the shredding and electrostatic separation processes. The size of these particles is significant for further material applications, such as being used as a filler in concrete instead of gravel (influencing mechanical properties). The tested granulate A was obtained during shredding in a machine equipped with a screen with 1.5 mm diameter openings, while granulate B was obtained during shredding with a machine equipped with a screen with 1 mm diameter openings. In the case of granulate A, originating from the shredding process with a 1.5 mm screen, the main fractions were: 65.5% above 1.4 mm, 27.4% between 1.4 mm and 1 mm, and 7% below 1 mm. Granulate B, derived from the shredding process of electrical cables with a 1 mm screen, showed a more diverse fraction distribution than granulate A. The dominant fraction was between 1 mm and 0.71 mm (34.1%), followed by 0.71 mm to 0.5 mm (28.2%), and 0.5 mm to 0.25 mm (28.8%). The extreme fractions - above 1 mm and below 0.25 mm - constituted 1.4% and 7.5%, respectively. A smaller screen (1 mm) leads to a more varied fraction distribution, with a higher proportion of smaller particles, resulting in higher bulk density and improved potential for applications such as concrete fillers. This knowledge can contribute to a better understanding of the mechanical properties of materials utilizing these granulates as fillers in their structure.

Keywords: shredding electrical wires, sieve analysis of fractions, particle size, Polyethylene Terephthalate (PET), Polycarbonate (PC), Polyvinyl Chloride (PVC), High-Density Polyethylene (HDPE), High Impact Polystyrene (HIPS), concrete filler

Introduction

There is an increase in the production of plastic products worldwide [1]. Due to their extensive consumption, environmentally friendly methods for their reuse are being sought [2–4]. Currently, there are three main methods for disposing of plastic waste: incineration for energy recovery [5], recycling [6–8], and landfill disposal [9]. However, incineration is associated with the emission of heavy metal pollutants, which poses a direct threat to the environment [10]. Landfill disposal, in turn, leads to issues such as soil drainage blockages and water contamination [11]. For these reasons, the search continues for methods of recycling that are both environmentally safe and cost-effective. Electrical wires and cables are subject to recycling, where the plastic insulation is stripped from the copper or aluminum core and then shredded [12]. The recyclate obtained from cable insulation comprises various materials, including Polyethylene Terephthalate (PET), Polycarbonate (PC), Polyvinyl Chloride (PVC), High-Density Polyethylene (HDPE), and High Impact Polystyrene (HIPS) [13]. Due to the frequent mixing of recyclates from different cables, determining the exact composition of such agglomerates is often challenging.

Due to the various material properties crucial for proper processing during extrusion or injection molding, recyclate is used as a filler in concrete. The use of plastic-derived fibers, such as Polyvinyl Alcohol (PVA) and Polypropylene (PP), as fillers in concrete mortar improves its strength properties and offers economic benefits [14]. Recycled fiberglass from water equipment can also be used as a filler in concrete. PVA and steel fibers (SE) have been incorporated into concrete mortar. These fibers act as both fillers and reinforcement for the concrete mix. They help reduce the formation of microcracks and enhance the strength properties of the material.

Developing new composites based on waste materials represents a significant research direction [15]. Studies such as those by Borawski et al. (2024) [16] and Mancel et al. (2022) [17] highlight the broad potential of recycled materials. For example, flax fibers can be used to reinforce friction composites, while waste rubber can improve the fire resistance of wooden composites. Additionally, wood-plastic composites (WPCs) from recycled wood and plastic can be used for various outdoor applications [18]. Eco-efficiency analyses, such as those conducted by Joachimiak-Lechman et al. (2019) [19], demonstrate that innovative waste utilization can contribute to environmental protection and economic sustainability. In the context of waste processing technologies, new separation methods play a crucial role, such as tribo-electrostatic separation described by Łyskawiński et al. in 2021 [20], or advanced plastic shredders that enable the production of granulate with specific particle size fractions.

Shredding of materials is an energy-intensive process; however, it provides additional advantages by facilitating transport, processing [21,22], and storage [23–25].

Depending on the type of recyclate material and, most importantly, its particle size, concrete with such filler will exhibit varying mechanical properties. For this reason, an important objective has been to study the particle size fractions of granulate obtained from the recycling of electrical cables.

1. Results and discussion

The study focused on copper electrical wires from automotive harnesses (excluding fuse boxes, clamps, and plastics). The permissible range of wire diameters for shredding, determined by the design of the shredding mechanism and the limitations recommended by the shredder manufacturer, was 0.5 to 25 mm. The shredding process was carried out using a Stokkermill K750 electrical waste shredder (Udine, Italy) with a machine power of 7.5 kW. The shredder has two types of mills, each featuring three rotating blades. Changing the screens in the machine enables the separation of two particle size fractions, which were analyzed in the study. The screen opening sizes used were 1.5 mm (granulate A) and 1 mm (granulate B).

After the shredding process, a mixture of copper and plastic particles remains. To separate the copper from the wire insulation material, a HAMOS KWS 10-10 electrostatic separator (Penzberg, Germany) was used (Fig. 1). The requirements for the input material include the following: dust-free material, uniform dimensions of 0.1–8 mm, moisture content < 0.2%, free flow without sticking, a mixture of conductive and non-conductive material, and particles that are fully liberated—not adhering to each other or permanently bonded. The average throughput of the separator is 150–500 kg/h.

The study analyzed the materials constituting the insulation of the electrical wires (Fig. 2) obtained from the separator, which processed the material prepared by the shredder using screens with openings of 1.5 mm (granulate A, Fig. 2a) and 1 mm (granulate B, Fig. 2b).

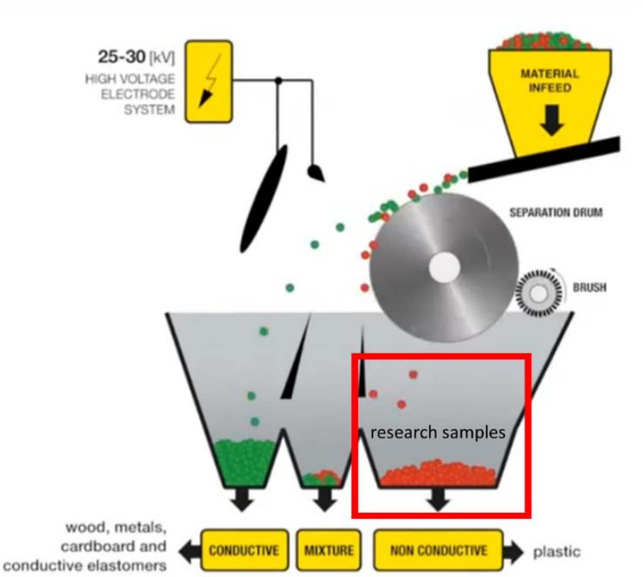

Fig. 1. – The sampling point for testing during the electrostatic separation process

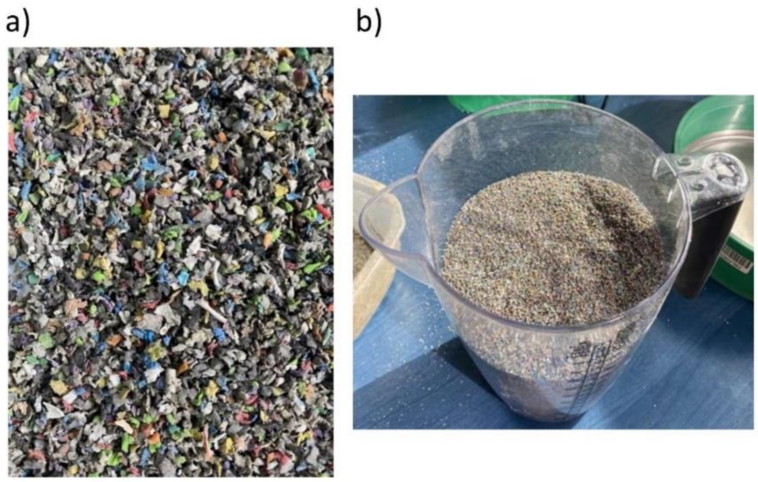

Fig. 2. – Plastic granulate constituting the insulation of electrical wiring in automobiles:
a) After the shredding process with a 1.5 mm screen; b) After the shredding process with a 1 mm scree

Granulometric composition was analyzed using a laboratory sieve shaker (model LPzE-2e, manufactured by Multiserw-Morek, Brzeźnica, Poland) [26]. Initially, the test samples were placed in a 100 ml container, and their mass was measured using a precision laboratory scale with an accuracy of 0.01 g (model 572-35, manufactured by

Kern & Sohn GmbH, Frankfurt am Main, Germany). The samples were manually compacted to avoid a loose fill. The material density for the tested volume was determined by measuring the mass with a known volume.

The material was then sieved through six sieves in the following sequence of mesh sizes: 2.5 mm, 1.4 mm, 1.0 mm, 0.71 mm, 0.50 mm, and 0.25 mm. This process resulted in seven fractions: greater than 2.5 mm, between 2.5 and 1.4 mm, between 1.4 mm and 1.0 mm, between 1.0 mm and 0.71 mm, between 0.71 mm and 0.50 mm, between 0.50 mm and 0.25 mm, and below 0.25 mm (Fig. 3). Each fraction was weighed after separation.

A total of 12 samples were prepared using granulate with finer fragmentation, and another 12 samples with coarser fragmentation. In cases where only a small quantity of particles remained on the sieves during the tests, the results from selected sieves were combined due to difficulties in accurately measuring very small masses (Fig. 4).

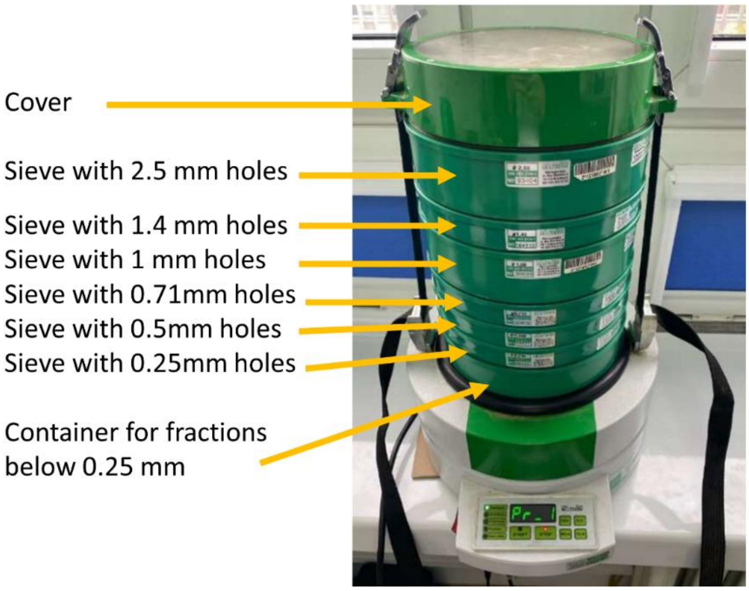

Fig. 3. – Laboratory Sieve Shaker LPzE-2e

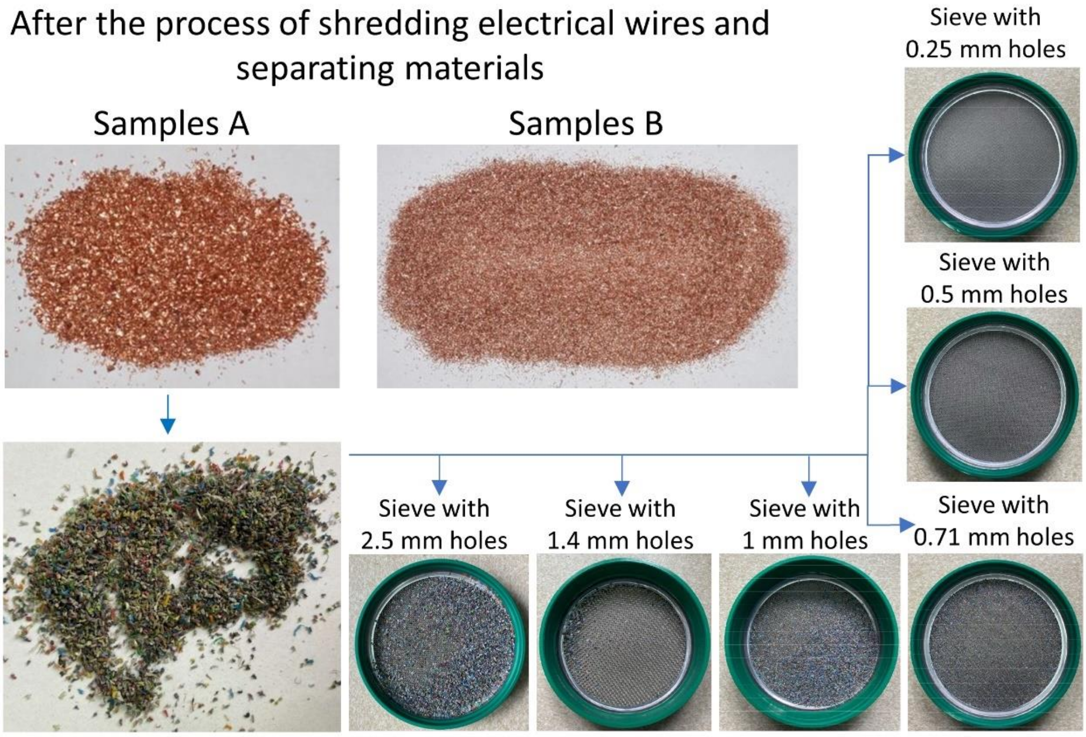

Fig. 4. – Distribution of fractions on sieves during testing

2. Methodology

The density analysis of granulate A (Fig. 5) and granulate B (Fig. 6) was conducted by measuring the mass of the granulate in a cylindrical container with a volume of 100 ml. Initially, the results were expressed in grams per 100 ml, but for consistency with the International System of Units (SI), they were converted to kilograms per cubic meter (kg/m³). The average density of granulate A was 444.7 kg/m³, while granulate B had an average density of 545.3 kg/m³.

The higher density of granulate B is understandable, as it consists of smaller particles that more effectively fill the available volume, reducing interparticle voids. Similar relationships between particle size and bulk density have been observed in studies on the properties of metallic powders. As noted by Otrębnik and Matula in 2010, smaller powder particles lead to higher bulk density due to better packing and reduced interparticle voids [27]. These findings align with our observations regarding granulates A and B, confirming that a reduction in particle size contributes to increased material bulk density.

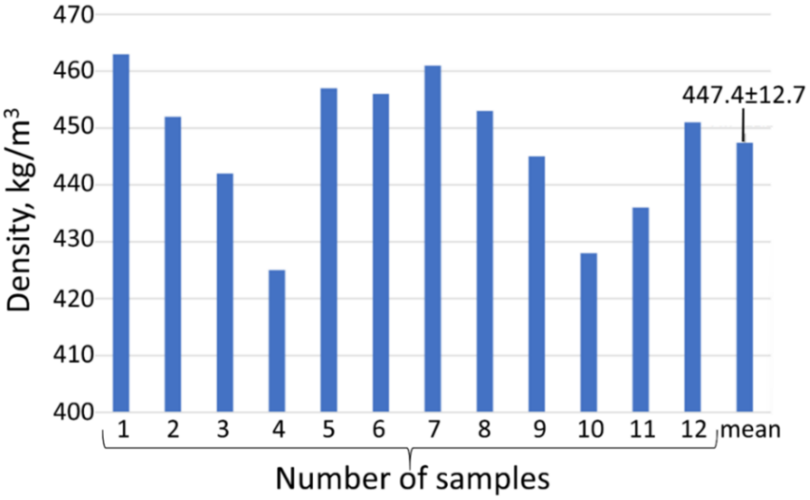

Fig. 5. – The density during the filling of the container with granulate A

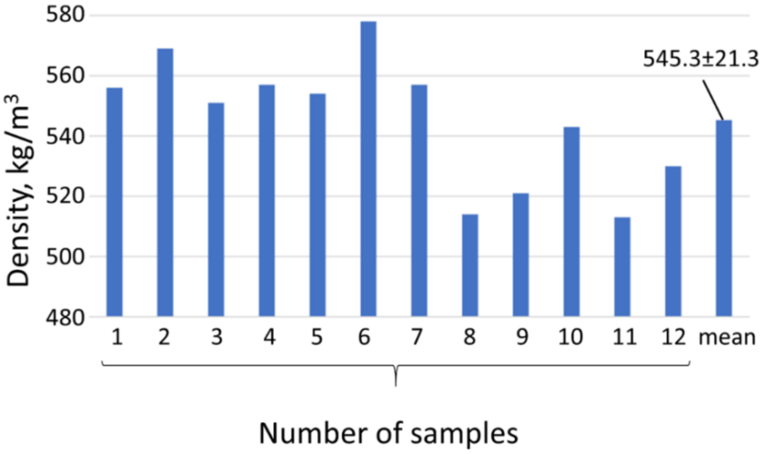

Fig. 6. – The density during the filling of the container with granulate B

The percentage contribution of specific fractions in the tested volume can be determined by knowing the total mass of the tested samples from the previous study and measuring the mass of the fractions deposited on individual sieves. The results of these studies are presented in Fig. 7 for granulate A and Fig. 8 for granulate B.

For granulate obtained from the shredding process using a machine with screens having a mesh size of 1.5 mm, the primary fractions were as follows: 65.5% above 1.4 mm, 27.4% between 1.4 mm and 1.0 mm, and 7% below 1.0 mm. While a larger number of sieves with different gradations were used during the tests, as shown in Fig. 4, some sieves collected very small amounts, which made measurements difficult. Consequently, selected fractions were grouped to increase the described range.

Granulate B, originating from the shredding process of electrical wires using a machine with a 1 mm mesh size, exhibited more dominant fractions than granulate A. The most prevalent fraction was between 1.0 mm and 0.71 mm (34.1%), followed by 0.71 mm to 0.5 mm (28.2%), and 0.5 mm to 0.25 mm (28.8%). Extreme fractions above 1 mm accounted for 1.4%, while those below 0.25 mm constituted 7.5%.

Studies conducted by other researchers, without specifying the detailed settings of the shredding machines, indicate that 85% of particles resulting from the shredding process of electrical wires are larger than 0.5 mm [28]. This is closely aligned with the results presented in this article. Wędrychowicz et al. in 2023 discussed how the granulation process influences the liberation of metallic and plastic components, noting that optimal particle sizes are critical for effective separation techniques, such as electrostatic and density-based methods. The average particle sizes during their studies ranged from 0.34 mm to 0.59 mm. After separating the plastic material, particle sizes ranged from 0.01 mm to 0.13 mm (for copper) and 0.25 mm to 0.33 mm (for plastic material) [29]. The particles in their study were within a similar size range as those observed in this research.

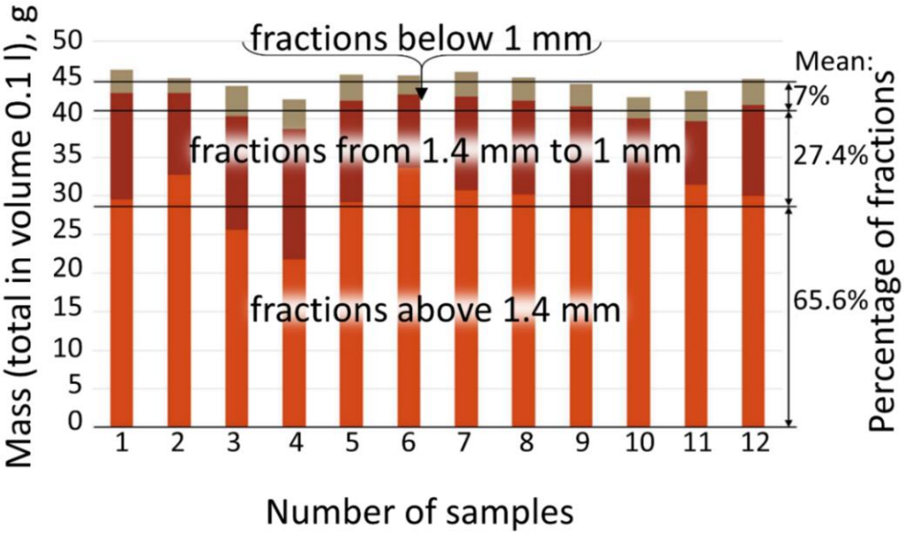

Fig. 7. – Fraction content in granulate A

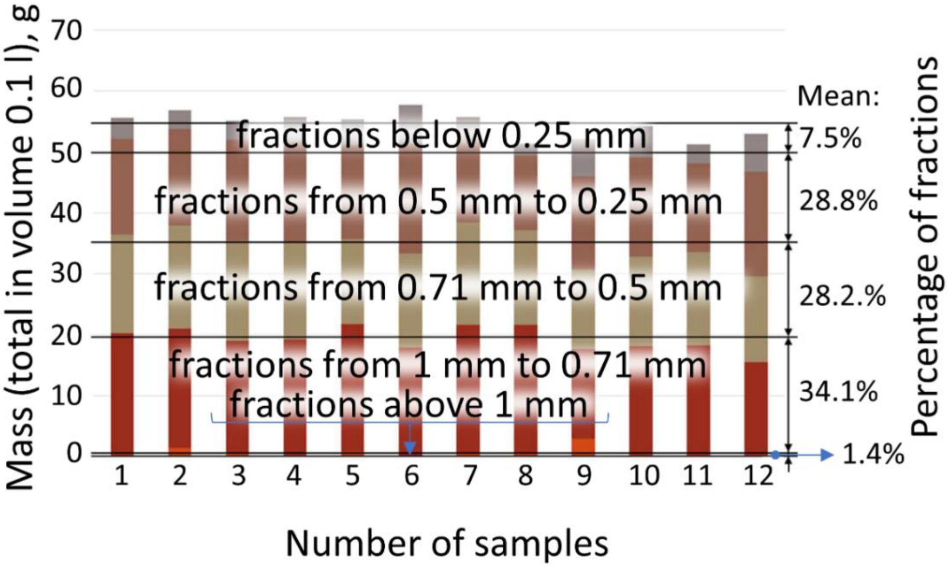

Fig. 8. – Fraction content in granulate B

The concept of using granulate derived from the recycling of electrical cable insulation presents an alternative to components made of carbon fiber in applications where dynamic loads are not significant. An example of such an application is a wheelchair [30], where a composite frame made of carbon fiber and epoxy resin can be replaced with a composite in which the carbon fiber reinforcement is substituted with polymer fractions obtained from the shredding of cable insulation. In this context, the fraction size is crucial, as its dimensions directly influence the mechanical properties of the final product. The information about the granulate fraction size is also essential for assessing slip risk on surfaces in buildings [31]. This issue becomes particularly important in modern buildings, where construction materials, such as tiles containing recycled plastic granules, are used. The fraction size affects the texture and functional properties of the surface, which directly impacts user safety. Another example of the significance of fraction size information is its application as a component in wheelchair tires. The size of the fraction used affects the mechanical properties of the tire, including rolling resistance [32]. This information is essential during the design and optimization of drive systems and structural components, as highlighted in studies on drive systems [33].

Conclusion

The study on the particle size distribution of plastics derived from the recycling of electrical cable insulation revealed a significant impact of shredding parameters on the properties of the obtained granulate. It was found that using a screen with larger openings (1.5 mm) resulted in granulate A with a coarser particle structure, where 65.5% of the particles exceeded 1.4 mm in size. Conversely, a screen with smaller openings (1 mm) produced granulate B with a finer particle distribution, dominated by fractions ranging from 1.0 mm to 0.71 mm (34.1%). The bulk density analysis showed that granulate B exhibited a higher density (545.3 kg/m³) than granulate A (444.7 kg/m³), attributed to better packing efficiency due to smaller particles filling void spaces more effectively. These results highlight the importance of particle size distribution for potential applications of recyclates, particularly as fillers in concrete, where finer particles can improve the material's mechanical properties by enhancing integration and structural reinforcement. Moreover, using a smaller screen size increases the diversity of particle fractions and optimizes the separation of conductive (copper) and non-conductive (plastic) materials during electrostatic separation. From an environmental perspective, the study emphasizes the significance of tailoring recycling process parameters to improve efficiency and minimize environmental impact. The findings provide valuable insights for optimizing recycling processes, enhancing the quality of recyclates, and expanding their applications in developing sustainable materials.

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