

A Review on Fraction-Wise Utilization of Wire-Cut Cable Insulation Waste for Construction and Composite Applications

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Abstract

Wire-cut insulation waste generated during cable processing and e-waste recycling is often discarded due to its mixed composition, irregular particle size, and limited direct reuse options. However, this waste contains valuable polymeric materials and mineral fillers that can be effectively repurposed when properly understood. This review focuses on the characterization and utilization potential of wire-cut cable insulation waste, with special emphasis on size-based fractionation and construction-related applications. Existing studies highlight that cable insulation waste mainly consists of plasticized polyvinyl chloride (PVC), polyethylene-based polymers, and a significant amount of calcium carbonate (CaCO₃) filler, along with trace amounts of residual copper. Characterization techniques such as sieve analysis, Fourier Transform Infrared Spectroscopy (FTIR), and X-ray Diffraction (XRD) are commonly used to identify particle size distribution, polymer composition, and crystalline mineral phases. These techniques provide critical insight into how different fractions of the waste behave in composite and construction materials. This review discusses how sieve-based separation enables fraction-wise utilization of insulation waste, where coarse fractions act as lightweight aggregates or cushioning fillers, medium fractions contribute to acoustic and insulation performance, and fine fractions behave as mineral-rich fillers suitable for cementitious and resin-based composites. Applications in lightweight concrete, cement mortar, quarry dust blends, and resin-bonded panels are highlighted from recent literature. By adopting a fraction-wise approach rather than treating insulation waste as a single bulk material, improved material performance, better resource efficiency, and reduced environmental impact can be achieved. The review also identifies current research gaps and future opportunities for optimizing mix design and performance evaluation, supporting the sustainable integration of wire-cut insulation waste into construction and composite materials.

Keywords: Wire-cut insulation waste, Size-based fractionation, Polyvinyl chloride (PVC), Construction materials, Cementitious composites.

1. Introduction

The rapid growth of the electrical, electronics, and telecommunication sectors has steadily increased waste generated from cable manufacturing, wire processing, and recycling. Among these waste types, wire-cut insulation waste is significant but often overlooked. During cutting, stripping, and copper recovery, the metallic conductor separates from the surrounding insulation layer, which remains as irregular fragments, shredded pieces, and fine residues. Often, this material is simply thrown away without a clear plan for reuse, even though it still

contains valuable polymer and mineral components. Managing wire-cut insulation waste is challenging because of its mixed nature, non-biodegradability, and chemical stability. It typically contains insulation polymers like polyvinyl chloride (PVC), polyethylene (PE), or other cable-grade materials. It also includes additives such as plasticizers, stabilizers, pigments, and mineral fillers like calcium carbonate (CaCO₃). Small traces of metallic copper can sometimes remain in the insulation residue after separation. Due to its mixed composition, this

material is usually seen as low-value waste instead of a usable secondary resource. However, improper disposal leads to environmental problems and the loss of materials that still have recycling and engineering potential. The main issue is not just the creation of this waste, but also the lack of a practical way to use it. Copper recovery from used cables is well established because copper has direct commercial value. In contrast, the insulation component is often ignored because of its diverse particle size and difficulty fitting into traditional recycling systems. Consequently, a material stream rich in polymers and fillers remains underutilized. With the growing interest in sustainable construction materials and waste-based composites, this insulation residue has started to gain attention as a possible raw material for lightweight fillers, composite boards, mortar blends, and other low-density construction products. To determine if this waste can be reused effectively, proper material characterization is crucial. Simple visual observation is not sufficient because wire-cut insulation waste contains a mix of different particles, polymers, fillers, and occasional metal traces. Techniques like sieve analysis help understand particle size distribution, while FTIR and XRD are useful for identifying polymer types, filler compositions, and crystalline phases present in the material. Preliminary observations indicate that a large portion of the waste falls within the medium-to-fine particle range. This suggests it may serve well as a fine, well-graded filler suitable for blending in composite and construction applications. It is clear that this waste should not be treated as a single bulk material but as a resource with various potential uses. In this context, the current review focuses on the composition, characterization, and application potential of wire-cut insulation waste, particularly its use in construction and composite materials. The review emphasizes the importance of understanding the different fractions and explains how various particle sizes may be directed toward different engineering applications. By shifting from disposal-oriented thinking to targeted reuse, wire-cut insulation waste can be viewed not just as a waste issue, but as a valuable secondary material for sustainable recycling and resource circularity [1].

2. Material Composition and Characteristics of Wire-Cut Insulation Waste

Wire-cut insulation waste is a kind of waste that is made when cables are cut, stripped and copper is recovered. People often think it is not very useful. It actually has a lot of good things in it that can be used again in many different ways. To know how we can use it again we need to look at what it's made of and how it behaves. Cable insulation is mostly made from materials like polyvinyl chloride, polyethylene and cross-linked polyethylene. Polyvinyl chloride is commonly used in cables that do not have high voltage because it is flexible a good insulator, not expensive and easy to work with. Usually the insulation is not just made of one type of material it also has things added to it like plasticizers, stabilizers, colorants, flame retardants and mineral fillers. These things help the insulation work better when it is being used and when it is being made Shown in Figure 1.



Figure 1 Granulated Multicolored Plastic Waste Particles for Recycling Analysis

One important thing about wire-cut insulation waste is that it has a lot of calcium carbonate in it. This is added to the insulation to make it cheaper to make it keep its shape and to make it stronger. So we should not think of this waste as a simple plastic waste. It is actually a mix of polymer and mineral. Both of these parts affect how it behaves. This is especially important when we think about using it in construction or to make composites. When we look at wire-cut insulation waste using tools we can see that it has a lot of the things we would expect. It has signs of the polymer backbone signs of the plasticizers and signs of the mineral fillers [2]. All of these things tell us that the waste is mostly made up of polyvinyl chloride with mineral fillers Shown in Figure 2.



Figure 2 Shredded Mixed Plastic Fragments Collected for Recycling and Material Analysis

Wire-cut insulation waste can also have amounts of copper in it left over from when the copper was separated from the insulation. This copper is usually only present in amounts but it still adds value to the waste. The amount of copper can vary depending on the type of cable. How well the copper was recovered. This means that not all wire-cut insulation waste is the same, which is why we need to test it before we can reuse it. The way the waste looks and feels can also change depending on how the cable was processed. After it is cut or shredded the insulation can be in the form of flakes, strips or powder. The bigger pieces are usually more flexible while the smaller pieces can be more rigid and have more of the mineral fillers in them. This affects how dense the waste is, what the surface is like how rigid it is and how well it mixes with materials. Wire-cut insulation waste is also very durable. It is made from polymers that do not break down easily. It does not decompose and it can last for a long time. This can be a problem if the waste is just thrown away. It is a good thing if we can find a way to reuse it. The waste can also resist moisture. It is not very dense which makes it a good choice for construction and composite materials. However wire-cut insulation waste is not perfect. Because it is made from a mix of materials and has polymers that do not like water it can be hard to get it to bond well with materials like cement. The shape of the particles can also make it hard to compact and get a mix. So while the waste has a lot of potential for reuse we need to process it and make sure it is compatible with other materials before we can use it. Wire-cut insulation waste is a material that should not be thrown away. It is made from a mix of polymers,

mineral fillers and small amounts of metal. It has a lot of potential for reuse. The first step, in reusing this material is to understand what it is made of and how it behave [3].

3. Fractionation and Characterization Techniques

Fractionation and characterization of wire-cut insulation waste are really important to understand what this waste is and how it can be reused. This waste is not all the same it comes in sizes, shapes and is made up of different things so we cannot treat it like it is all one material. Some parts of it are richer in polymers while other parts have filler content or tiny particles that feel like dust. To get an understanding of wire-cut insulation waste we need to separate it into different parts and study each part on its own. This gives us a clearer idea of how the waste behaves and where it can actually be used. The first step in doing this is to separate the particles by size. We use a technique called sieve analysis, which's very simple and useful. In this method the shredded wire-cut insulation waste is passed through a set of sieves that have different mesh sizes. This helps us divide the material into medium, fine and very fine parts. We do this because each part behaves differently Shown in Table 1.

Mesh Size	Weight Retained (kg)	% Weight Retained	Cumulative % Retained	% Passing
6	0.004	0.40%	0.40%	99.60%
10	0.504	50.40%	50.80%	49.20%
30	0.322	32.20%	83.00%	17.00%
170	0.100	10.00%	93.00%	7.00%
Pan	0.070	7.00%	100.00%	0.00%

Table 1 Sieve Analysis Results of Shredded Plastic Particles Showing Size Distribution and Percentage Retention

The bigger particles still have a lot of the polymer structure and are more flexible while the smaller particles have more exposed mineral filler and behave more like granular material [4]. Looking at how the particles are distributed by size also gives us a practical idea of whether the waste can be used for

blending. In a sample of wire-cut insulation waste most of the particles are usually in the medium to fine range. A lot of the material falls between about 2 mm and 0.6 mm which shows that the waste behaves like a fine well-graded filler than a coarse plastic scrap Shown in Figure 3 - 5.

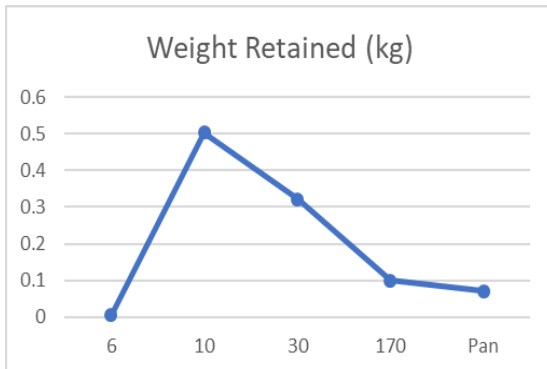


Figure 3 Variation of Weight Retained Across Different Mesh Sizes in Sieve Analysis

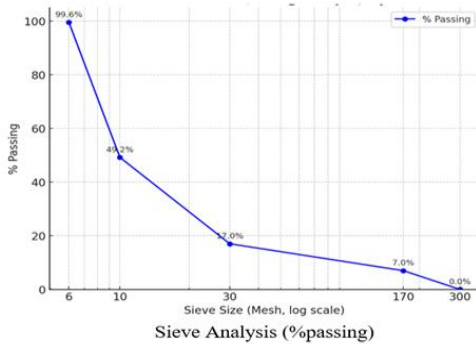


Figure 4 Sieve Analysis Curve Showing Percentage Passing Versus Mesh Size (Log Scale)

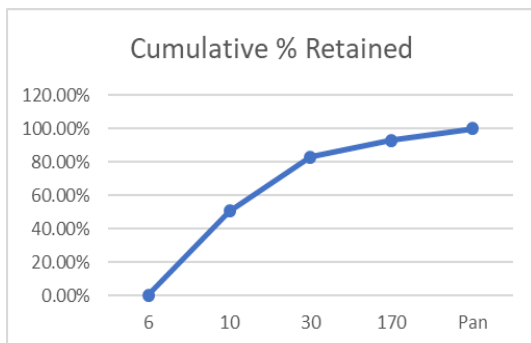


Figure 5 Cumulative Percentage Retained Across Mesh Sizes in Sieve Analysis

We can use things like D10, D30 and D60 along with

the uniformity coefficient to understand whether the material is broadly graded or narrowly distributed. If the distribution is broad and well-graded it is generally more favourable for blending because it improves packing and reduces void formation. Once we have separated the parts we use chemical and structural characterization techniques to study their nature in detail. One technique we use is called Fourier Transform Infrared Spectroscopy or FTIR. This technique helps us identify the components present in the wire-cut insulation waste Shown in Figure 6.

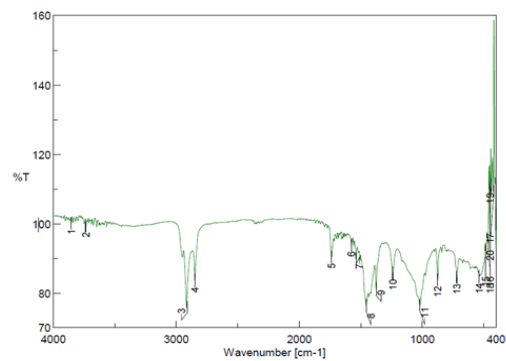


Figure 6 FTIR Spectrum of Plastic Sample Showing Transmittance vs. Wavenumber

FTIR works by detecting the groups in the material based on their infrared absorption pattern [5]. It is especially useful for confirming whether the waste contains things like PVC, PE or XLPE. FTIR also helps us identify the presence of plasticizers and carbonate-based fillers Shown in Table 2.

Peak (cm ⁻¹)	Assignment	Comment
2916, 2849	C-H stretching (CH ₂ /CH ₃)	Polymer backbone -hydrocarbon signals (PVC/PE)
1738	C=O stretching	Ester carbonyl - indicates plasticizer (phthalate/ester) present.
1576, 1541	Aromatic ring vibrations	Consistent with phthalate plasticizer aromatic moiety.
1239	C-O / C-O-C stretch	Ester linkages from plasticizer or additives.
1019	Si-O or C-O	Possible contamination or minor additive
874, 719	Carbonate out-of-plane bending / CH ₂ rocking	CaCO ₃ filler signature -very strong.

Table 2 FTIR Peak Assignments and Functional Group Analysis of Plastic Sample

In wire-cut insulation waste this technique generally confirms that the material contains a polymer phase along with significant mineral filler content. Another important technique we use is called X-ray Diffraction or XRD. While FTIR provides information about chemical bonds and functional groups XRD helps us identify the crystalline phases in the sample [6]. This is particularly useful for confirming mineral fillers like calcium carbonate and detecting traces of copper. Since polymers like PVC are mostly amorphous they do not show diffraction peaks. In contrast crystalline fillers and metal particles appear clearly in the XRD pattern. Because of this XRD gives us support in distinguishing polymer-rich parts from filler-rich parts Shown in Figure 7.

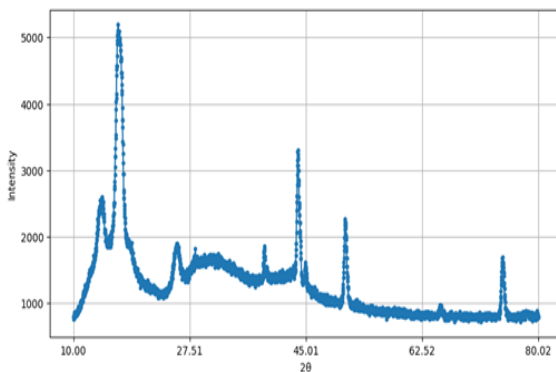


Figure 7 X-Ray Diffraction (XRD) Pattern of Plastic Sample Showing Intensity vs. 2θ

Apart from FTIR and XRD we also do physical and visual examinations of each part. This gives us supporting information. Things like particle shape, flexibility, roughness, colour variation and powder-like behaviour can all indicate differences in composition and material structure. For example, big flakes often appear elastic and polymer-dominant while very fine parts may look chalky and behave more like mineral powder. Even though these observations are basic they help us connect the results from our instruments with how the material behaves. It is also important to remember that fractionation and characterization should not be seen as tasks. They work best when used together. Sieve analysis tells us how the waste is physically distributed FTIR gives us information about the additive composition and XRD identifies the crystalline filler and metal phases.

When we combine these results we can understand the waste in a more practical way. Of just calling it a mixed cable residue we can identify which part is suitable for lightweight filling, which one is better for acoustic or insulation products and which one can act as a fine filler in cement or resin-based systems. In studies this kind of understanding is what makes the reuse strategy more meaningful. Without it the entire waste stream is treated as one material, which often leads to poor consistency and weak application mapping. By dividing the waste based on size and then characterizing each part properly we can assign the material to suitable applications with better technical reasoning. Fractionation and characterization techniques are the base for the reuse of wire-cut insulation waste. They help convert an industrial residue into a better-defined material stream by linking particle size, composition and structural behaviour. This understanding is essential, for developing reuse strategies especially when the material is being considered for construction and composite applications. Wire-cut insulation waste can be reused in an effective way if we understand what it is made of and how it behaves [7].

4. Construction and Composite Applications

The use of wire-cut insulation waste in building materials and composite materials is getting attention for two reasons. First there is a lot of this waste from cable recycling and processing. Second it has some properties like being light resistant to moisture having filler content and being durable. Although it cannot replace building materials in all cases it can still be useful in certain non-structural and semi-structural applications. One of the uses of wire-cut insulation waste is in making lightweight cement materials. Since it is lighter than fine aggregate adding it to mortar or block mixtures can make the final product lighter. This is helpful in making partition blocks, filler blocks, lightweight wall panels and non-load-bearing elements. The polymer part helps reduce density while the mineral filler, calcium carbonate may help with filler packing. At the time we need to carefully control how much of it we add, because too much polymer can reduce compressive strength due to weak bonding with cement paste. The wire-cut insulation waste is really helpful, in these applications. The use of wire-cut insulation waste can

make building materials lighter [8-10]. The properties of wire-cut insulation waste make it a useful material. Wire-cut insulation waste can be used in place of some aggregate in mortar and low-strength concrete. We can mix medium wire-cut insulation waste with sand or quarry dust to make low-density composite mixes Shown in Figure 8.



Figure 8 Prepared Concrete Test Specimens (Bricks/Blocks) for Compressive Strength Evaluation

In these systems the waste is mainly used as a filler not to give strength. This is useful when we want to reduce the weight of the material lower the cost or improve insulation. We do not need it to be very strong. Quarry dust-based composites are another way to use wire-cut insulation waste. Quarry dust is already used as an alternative to natural sand in many construction products. When we combine wire-cut insulation waste with quarry dust we get a mix of mineral particles and lightweight polymer fragments. This combination helps to balance stability and weight reduction. Fine wire-cut insulation waste can blend well with quarry dust. Improve the mix. We can use these mixes to make low-cost blocks, interior boards and paving units. Wire-cut insulation waste can also be used to make resin-bonded composites. In these products the waste is used as a filler. Is combined with binders like epoxy or polyurethane. Since the waste already contains polymer material it can work well in resin-based systems. We can use medium fractions to make porous lightweight boards and finer fractions to improve the surface finish. These composites can be used to make panels, partition boards and acoustic products. Wire-cut insulation waste is also good for acoustic insulation.

The waste can trap air within its structure, which reduces heat transfer and improves absorption. Medium and coarse fractions are better for this because they maintain voids. We can use wire-cut insulation waste to make boards, insulation panels and sound-damping layers. Apart from construction wire-cut insulation waste can be used to make composite products for other applications. These may include furniture, protective sheets, packaging inserts and cushioning layers. In these cases the value of the material lies in its cost, weight reduction and durability. The use of wire-cut insulation waste in construction and composite applications depends on the particle size, composition and end-use requirement. It is not a universal replacement material. It has value in products where lightweight character, insulation performance and partial filler action are beneficial. With processing and control this waste can help to develop sustainable and low-cost material systems. Wire-cut insulation waste can be very useful, in applications, including construction and composite products when we use it in the right way. The key is to find the right mix and use of wire-cut insulation waste to get the benefits we need.

5. Fraction-Wise Utilization Strategy

Wire-cut insulation waste is a problem because it is made up of many different things. The size of the particles the texture of the surface the amount of polymer and the amount of filler are all different throughout the material. This makes it hard to use the waste in its form. The best way to deal with wire-cut insulation waste is to separate it into size groups. The coarse group has flakes and strips that are still a bit like the original insulation. These particles are light flexible and do not pack together well. Because of this the coarse wire-cut insulation waste is better for things like filler boards, cushioning sheets and acoustic filling. It can also be used in layers that are not very heavy. The medium group of wire-cut insulation waste is usually the useful. The particles in this group are smaller and more consistent than the group. They still have some of the structure, which helps with the texture and voids. At the time they have more filler on the surface which makes them work better with binders. This makes the medium wire-cut insulation waste good for boards, composite panels and certain mixes of cement. The fine group

of wire-cut insulation waste is different because it is like sand and has a lot of exposed mineral filler. It mixes well with sand, cement and resin systems. This makes it good for things like low-density blocks, mortar and molded boards. The fine wire-cut insulation waste can also help make the surface of molded products smoother. The fine group of wire-cut insulation waste is like powder and behaves more like a micro-filler. It has a lot of mineral- particles and helps with the packing and surface smoothness of products. In resin-based systems it can help fill gaps and make the matrix more consistent. However, it is hard to handle because it can create dust and health problems. The best thing about separating wire-cut insulation waste into size groups is that it allows each group to be used in the best way possible. Of trying to use all the waste in one product this approach lets each size group be used where it works best. The coarse wire-cut insulation waste can go into products the medium wire-cut insulation waste into balanced composite systems the fine wire-cut insulation waste into filler-based applications and the very fine wire-cut insulation waste into matrix modification roles. This approach is also good from a point of view. It is expensive and often not possible to separate the polymers in cable waste. Separating wire-cut insulation waste into size groups is a simpler and more realistic way to upgrade the waste into useful materials. It does not require high-end purification, which makes it more feasible for use. Overall separating wire-cut insulation waste into size groups turns a problem into an advantage. Of seeing the variability of the waste as a problem this approach uses it to develop targeted applications. It provides an more reliable path, for reusing wire-cut insulation waste in construction and composite materials

6. Challenges, Research Gaps, and Future Scope

Wire-cut insulation waste has a lot of potential for reuse. However, there are challenges that limit its use. These challenges are related to the material being different each time compatibility issues, safety concerns and not having data on how it performs. Because of this we need to do research that focuses on how to use the material. One of the challenges is that the waste is made up of different things. The type of polymer the amount of filler the level of additives and the amount of metal residue can all vary

depending on the type of cable that was used and how it was recovered. Some batches of wire-cut insulation waste may have PVC while others may have more PE, XLPE or a mix of insulation materials. The amount of calcium carbonate and copper residue can also be different each time. This makes it hard to develop a way of using the material. When the particle size is the same the actual composition of wire-cut insulation waste can still be different and affect how it performs. Another challenge is that the particles in wire-cut insulation waste do not bond well with cement. Most cable insulation particles are hydrophobic. Do not react well with chemicals, which means they do not stick well to cement paste. Their smooth surface also makes it harder for them to bond. Because of this adding wire-cut insulation waste to mortar or block mixes can make them weaker. In systems that use resin the compatibility of wire-cut insulation waste may be better. The cost of the resin and how it is cured become important factors. This shows that using wire-cut insulation waste successfully depends on choosing the mix and method of processing. Wire-cut insulation waste is also a concern when it comes to fire and heat. Since many insulation materials are made of polymers they can melt, break down or release gases when it gets hot. This is especially important in buildings where fire safety's a must. Wire-cut insulation waste that contains PVC can release gases when it burns or breaks down. Even though mineral fillers like calcium carbonate can make wire-cut insulation waste a little more stable when it comes to heat we still need to do studies on how it performs in a fire before we can recommend using it in buildings. There is not research on how wire-cut insulation waste performs. Many studies talk about what the material's made of and how it can be used but not many studies give complete data on how strong it is, how it absorbs water and how it lasts over time. In some cases wire-cut insulation waste is suggested for use in construction based on basic tests. For real-world use this is not enough. We need to test the material in the conditions it will be used in. Another gap in research is that there are not studies that try to find the best way to use wire-cut insulation waste. The performance of wire-cut insulation waste depends on things, including the size of the particles the amount

of waste used the type of binder the water-to-cement ratio, the curing time and the presence of other materials like quarry dust. However, many studies just try things and see what works. We should use tools like Design of Experiments and Response Surface Methodology to find the combinations for strength, density and insulation. Wire-cut insulation waste also needs to be tested on a scale. Just because it works in a test does not mean it will work in a real-world setting. At a scale thing like how well the material can be separated, stored and handled become important. The cost of processing wire-cut insulation waste and how it works with existing equipment also need to be considered. A product that works well in a test may not work as well when made on a larger scale. Future research should include testing wire-cut insulation waste on a scale and doing a simple economic assessment. There is also a need for advanced testing and long-term validation of wire-cut insulation waste. Techniques like scanning electron microscopy and thermogravimetric analysis can give us an understanding of the material. For use in construction we need to study how wire-cut insulation waste lasts over time when exposed to water, heat and chemicals. The future of wire-cut insulation waste is still wide open. It can be used in building blocks, acoustic panels, quarry dust-based composites, hybrid polymer-mineral boards and low-density partition materials. The promising way to use wire-cut insulation waste is not just to find a way to use it but to develop products that are designed to perform well. This is where recycling wire-cut insulation waste becomes more than getting rid of waste but a way to design materials. Overall we have a starting point but we need to do more research that is practical and standardized. Future work should focus on making the material more consistent improving how it bonds with materials making it safer, in a fire finding the best mix and testing it on a larger scale. Then can wire-cut insulation waste go from a promising material in a lab to a reliable material that can be used in industry.

Conclusion

Wire-cut insulation waste is something we should really think about. It is created when we cut, strip and recover copper from cables. People often think it is worthless. It actually has some very useful things in

it like polymers, minerals and tiny bits of metal. So of just throwing it away we should think of it as something that can be used again. The thing is, wire-cut insulation waste is not just plastic waste. It is a mix of materials like polymers and minerals and how it behaves depends on the size of the pieces what is in it and how we process it. Some of the polymers in it like PVC and PE make it flexible and strong while the minerals, like calcium carbonate make it more rigid. This mix of materials is what makes it useful for some construction and building projects. To really be able to use it we need to understand what is in it and how it is made up. We can use tools, like sieves to separate it into different sizes and other tools like FTIR and XRD to figure out what materials are in it. This is important because each size and type of material behaves differently and we need to use it in the way. There are some good ways we can use wire-cut insulation waste. We can use it to make building materials like lightweight cement or to make panels that are strong and insulated. It can also be used to make things that keep sound or heat out. To get the best results we need to use it in a smart way not just throw it in with other materials. If we use the size and type of material for each project we can get really good results. At the time there are still some problems we need to solve. The material can be different each time we get it it can be hard to get it to stick to materials and we are not really sure how it will behave over time. So we need to do research and testing to make sure we can use it in a way that is safe and effective. Overall wire-cut insulation waste is something that can be really useful if we use it in the way. If we can figure out how to classify it test it and design products that use it we can turn something that is usually thrown away into something that's really valuable. The good thing, about this is not just that we can reduce waste but that we can turn something that is hard to get rid of into something that is really useful. Wire-cut insulation waste can be a part of making construction and building more sustainable. Wire-cut insulation waste has the potential to be a game changer.

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