Annales de Chimie - Science des Matériaux
Vol. 49, No. 1, February, 2025, pp. 1-6
Journal homepage: http://iieta.org/journals/acsm

Preparation and Evaluation Recycling Waste Polymers Composites

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https://doi.org/10.18280/acsm.490101

Received: 24 July 2024
Revised: 11 February 2025
Accepted: 19 February 2025
Available online: 28 February 2025

Keywords:
PVC, waste tire, bump, polymeric waste, recycling polymers

ABSTRACT

In this work, polymeric waste materials such as tires and PVC waste have been exploited in the manufacturing of industrial speed bumps. Tires were processed into granules of approximately 0.185 mm, and PVC waste was reduced to granules with a size of about 0.275 mm. These prepared granules were combined with silicone rubber and a hardening agent to form a cohesive binder. Different prototypes were then crafted using varied proportions of tire to PVC waste specifically, 10%, 20%, 30%, and 40%. These prototypes underwent rigorous testing to evaluate their thermal conductivity coefficient, Shore A hardness, and compressive strength. It was observed that the prototype with a mix of 40% tire waste and 20% PVC waste exhibited the highest thermal conductivity. For hardness, the combination of 40% tire waste and 40% PVC waste achieved the highest Shore A value. However, the greatest compressive strength was exhibited by the prototype with a lower ratio of 10% tire waste to 10% PVC waste. Based on these results, the optimal compressive strengths of 2.25 MPa for the tire component and 2.12 MPa for the PVC. This composition was determined to be the most effective for the application envisioned in this work.

1. INTRODUCTION

A tire that is no longer used for the purpose for which it was originally made is referred to as a tire scrap, this tire, which is described as "junk", does not contain the technical requirements for recycling regeneration, but its material can be recovered through shredding, or grinding for use in many other applications such as shoes, sports surfaces, carpets, bumpers, etc. can also be used waste tires as fuel derived from tires for energy recovery. Defined as 'junk' due to their unsuitability for traditional recycling, tire scraps can still be valuable when shredded or ground for use in secondary applications like footwear, sports surfaces, and automotive parts, or as an alternative energy source [1]. The reclamation of materials from waste tires is especially critical considering the environmental hazards they pose, as they are a considerable source of pollution with the potential to release toxins into the air, water, and soil when decomposed, incinerated, or involved in fires [2]. Due to the very complex structure and composition of tire materials, it is difficult to recover and recycle used tires [3]. Continuous devulcanization is a method for recycling automotive tire rubber waste. With the new method developed, recycling can be deodorized during the process [4]. Exploring physical methods for processing automobile tires, grinding techniques stand out as a prominent approach to attain rubber crumb while preserving its essential properties [5]. The efficacy of mechanical rubber grinding hinges significantly on temperature and load application rates. Operating below the rubber's glass transition temperature induces small deformations and brittle destruction, making low-temperature physical methods a promising avenue for further exploration [6]. There are many comprehensive studies of waste tires, focusing on sustainability, environmental impact, and innovation in recycling. Several studies investigate incorporating waste tire rubber into products, polymer blends, and composites, emphasizing improved material performance and durability. Pacheco-Torgal et al. [7] emphasized using tire rubber in concrete, while Ramarad et al. [8] explained its evolving function in polymer blends. Machin et al. [9] focused on energy recovery methods like pyrolysis and gasification, which convert waste tires into valuable energy. Kida et al. [10] used experimental and computational approaches to assess the hazards of reusing recycled car tire materials. Environmental concerns are also addressed, with Kovochich et al. [11] examined tire and road wear particles in dust, illustrating their ecological risks, waste tires and plastics researches made significant strides in the past few years. Studies such as Palos et al. [12] examined waste refinery processes, converting end-of-life tires into valuable products. Pyrolysis, specifically for hydrogen production, has also been emphasized, with Sołowski et al. [13] providing an in-depth review of its potential. In addition, the reuse of recycled tire materials has raised concerns regarding safety and environmental impact. The applications of waste tires in construction, such as embankment protection against earthquakes, are evaluated by Hazarika et al. [14], and Sheraz et al. [15] studied their different properties in lightweight applications. Mayer et al. [16] emphasize the emerging environmental concerns associated with tire wear particles, and Abdullah [17] examined the sustainability of remanufactured tire products. Eco-friendly composite development, particularly through waste tire rubber particles, explored by Abohassan et al. [18] and Shaneei et al. [19], the studies contribute to developing the recycling. Polymeric waste such as tires and PVC is important for minimizing pollution and giving sustainability; also recycling materials transform waste into eco-friendly products by pyrolysis. Recycled the materials improve the durability and performance of construction products [20]. This study uses waste materials, offering an environmental solution by repurposing tire scrap in the manufacturing of industrial speed bumps.

2. EXPERIMENTAL WORK

2.1 Materials preparation

The Waste materials of tires compositions are shown in Table 1.

Table 1. shows the components of tires for cars and trucks

Materials	The Cars (wt%)	Trucks (wt%)
Rubber/Elastomer	48	45
Carbon Soot	22	22
Minerals	15	25
Texture	5	--
Zinc Oxide	1	2
Sulphur	1	1
Additives	8	--

Figure 1, consists of two images marked A and B. Both images are intended to depict different aspects of PVC (Polyvinyl Chloride) materials. Image A shows waste of PVC pipes, before it undergoes processing for recycling or for use as a raw material in creating new products or for experimentation. These pipes are commonly used for various plumbing and drainage applications. Image B shows a close-up view of a surface with red spots marked in circles, described as the grain size of PVC after milling. This a microscopic view that shows the granularity of the PVC material. The circled areas indicate points of particular grains. Grain size can be an important factor in determining the physical properties of materials, such as their strength, durability, or suitability for certain applications.

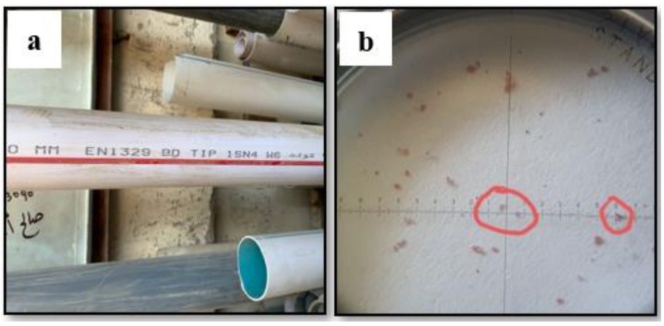


Figure 1. (a) Waste of PVC pipes, (b) Grain size of PVC

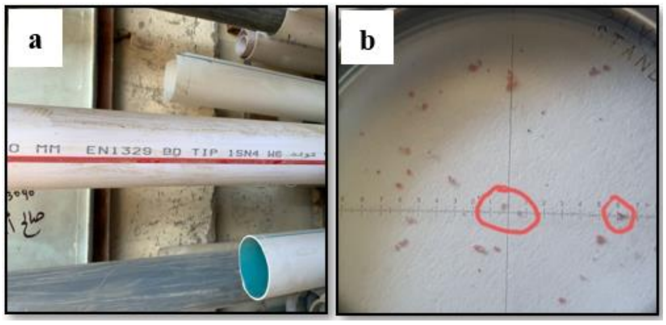


Figure 2. (a) Steel waste in tire, (b) Grain size of tire

In this research, crushed waste tire with a granular size (0.185 mm) was used and it contains (13.8%) steel (shown in the Figure 2), that has a number of properties that make it perfectly suitable for use as a basic material in the manufacture of bumps: Light weight, low-pressure, free-draining, good thermal insulators durable, and low-price.

Crushed waste PVC pipe with a granular size (0.275 mm) was used in the manufacture of bumps due to its properties: Extremely resistant to chemicals, thermal and electrical insulators, very lightweight, and low cost.

Figure 2, contains two images marked A and B, illustrating aspects of tire waste and its characteristics. Image A displays a collection of steel fibers or filaments that have been extracted from tire waste. These steel elements are often part of the internal structure of tires, providing reinforcement and contributing to the overall durability and shape retention of the tire under the stress of use. This image shows the steel waste as it appears after being separated from the rubber and other tire components, which part of a recycling material. Image B seems to be a close-up view of a surface with small fragments scattered across it, some of which are circled in red, described as the grain size of tire. This shows the rubber granules that result from grinding down tire waste, which can be used for various applications such as playground surfaces, athletic tracks, or as an additive in new tire manufacturing. The red circles indicate specific particles being examined for size, grain size can affect the physical properties and suitability for reuse in different applications, these images in Figure 2 appear to demonstrate the components recovered from tire waste and the detailed examination of the rubber granules' size, contributing to understanding the recycling process or the potential uses of the recovered materials.

Silicon rubber used in this work is a liquid with a slightly heavy texture. Base material (liquid rubber) and hardener, where for every 100 g of silicon, 2.65 g of hardener is added to it. Often shortened to grinder, is one of power tools or machine tools used for grinding, it is a type of machining using an abrasive wheel as the cutting tool. Each grain of abrasive on the wheel's surface cuts a small chip from the workpiece via shear deformation**.**

There are two methods for obtaining grains of polymeric waste materials:

-The method of freezing and then grinding into small parts,

-Grinding method by grinding wheel.

Where the grinding method was used in the preparation of the for the two materials tire and PVC.

Figure 3, features two images marked A and B, each displaying a different type of powder. Image A shows a white powder labeled as PVC, which stands for Polyvinyl Chloride. This type of plastic is known for its versatility and is used in a wide array of products from plumbing pipes to insulation for electrical wires. The white powder could be in the form of PVC resin, which is the base material for a lot of PVC products and is often processed further to produce various PVC goods. Image B displays a black powder "tire". This is likely to be ground rubber from used tires. Ground tire rubber is commonly recycled and used in various applications, such as in the creation of asphalt, artificial turf, or as an additive to new rubber products to improve certain properties or reduce costs.

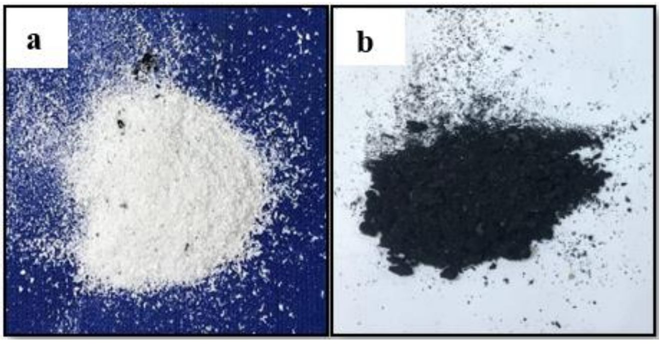


Figure 3. The powder (a) PVC, (b) Tire

Table 2 appears to show the varying weights of different materials (Tire or PVC, silicon rubber, and hardener) associated with different percentages of waste. The materials are measured in grams, and there are four distinct categories based on the percentage of waste (10%, 20%, 30%, and 40%).

Table 2. Weight of (Tire, PVC, Silicon rubber, and Hardener) with percentage of waste

Percentage of Waste	Tire or PVC Weight (g)	Silicon Rubber Weight (g)	Hardener Weight (g)
10%	3.84	32.95	0.89
20%	7.52	29.29	0.79
30%	11.28	25.63	0.69
40%	15.04	21.97	0.59

The pattern in the data indicates that as the percentage of waste increases, the weight of tire or PVC also increases, whereas the weight of silicon rubber and hardener decreases. This indicates that the process described in the table is substituting tire or PVC for silicon rubber and hardener as the waste percentage increases where the proportion of tire or PVC is being increased relative to the other components at higher waste percentages.

Figure 4. Shapes of samples

Figure 4 displays a lineup of cylindrical samples, each marked with a label that appears to indicate a number. These samples represent various mixtures or composites made from different materials, possibly including some of the materials mentioned in the earlier tables and figures, such as PVC or tire rubber. The different colors of the samples may be indicative of their composition, they include different proportions of materials or different types of additives. The black samples are typical of rubber composites, which are often black due to the addition of carbon black during processing to improve strength and durability. The white and other colored samples refer to the different fillers or the absence of carbon black.

2.2 Shore hardness test

Shore hardness test is a measure of the resistance a material has to indentation. There are different Shore hardness scales for measuring the hardness of different materials, such as soft rubbers, rigid plastics and super soft gels. Shore hardness, using either the Shore A or Shore D scale, is the preferred method for rubbers and thermoplastic elastomers – and is also commonly used for ‘softer’ plastics such as polyolefin, fluoropolymers, and vinyl's. The Shore A scale is used for ‘softer’ rubbers while the Shore D scale is commonly used for ‘harder’ ones. Hardness value is determined by the penetration of the Durometer indenter foot into the sample being tested, in this work used shore hardness type A.

2.3 Thermal conductivity coefficient test

Figure 5 illustrates the operation of the device used for measuring the thermal conductivity coefficient, a material property that indicates how efficiently a material conducts heat. The figure consists of two images, each highlighting different components of the measuring setup.

On the left side of the figure, an electronic device is shown, likely a power supply or a specialized instrument designed for thermal conductivity testing. It features various knobs and a digital display, allowing for precise adjustments and accurate measurements.

The right side of the figure depicts the practical application of the device, where it is connected to a sample using probes. Additionally, a vernier caliper is being used to measure the thickness of the sample, a crucial parameter in calculating thermal conductivity.

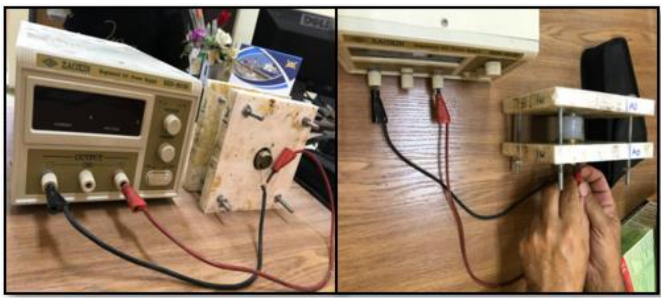


Figure 5. The thermal conductivity coefficient measuring device

Thermal conductivity coefficient of the sample can be estimated by the equation:

$$Ksample = k' \frac{t(T_2 - T_0)(T_1' - T_2')A'}{t'(T_2' - T_0')(T_1 - T_2)A}$$

$$\mathrm{K}' = 0.23 \frac{\mathrm{w}}{\mathrm{m}^2.\,°\mathrm{C}}, \mathrm{A}' = \frac{\pi}{4}(\mathrm{d})^2 = \frac{\pi}{4}(25)^2,$$

$$A = \frac{\pi}{4}(d)^2 = \frac{\pi}{4}(35)^2$$

d'=25 mm, d=35 mm,

t'=6 mm, $T_0' = 28°C$, $T_1' = 100°C$, $T_2' = 60°C$

where, K=Thermal conductivity coefficient of the sample, K'= Thermal conductivity coefficient of the standard material (Brian), A'= Area of the standard material (Brian), d'=Diameter, f the standard material, t'= thickness of the standard material, T_0'= constant surface temperature of the standard material, T_1' = first temperature of the standard material, T_2'= second temperature of the standard material, T_0= 40°C constant surface temperature of the sample, T_1= first surface temperature of the sample, and T_2= second surface temperature of the sample.

2.4 Compression test

A compressive test involves subjecting a material to a force applied from opposite sides, leading to its compression, crushing, or flattening. In this test, two plates cover the entire surface area of two opposite faces of the test specimen. These plates are positioned within a universal testing machine, which exerts a load on both faces, resulting in the flattening of the specimen. As the compressive forces are applied, the test specimen typically undergoes shortening and expansion perpendicular to the applied forces.

3. RESULTS AND DISCUSSION

Figure 6 is a bar graph representing the average hardness (measured on the Shore A scale) of three materials; Tire, PVC, and silicon rubber at various percentages of waste (10%, 20%, 30%, and 40%). The hardness of tire increases significantly with the percentage of waste, starting from 14.56 at 10% and going up to 34.94 at 40%. PVC also shows an increase in hardness with the percentage of waste, beginning at 16.02 at 10% and rising to 37.96 at 40%. Silicon rubber is only represented at 0% waste with a hardness of 10.22, with no data shown for higher waste percentages. This graph visually demonstrates the trend that as the percentage of waste increases, the hardness for both Tire and PVC materials increases as well. This is consistent with the data provided in one of the earlier tables you've shared, and the waste materials being added to tire and PVC likely contribute to an increase in their hardness.

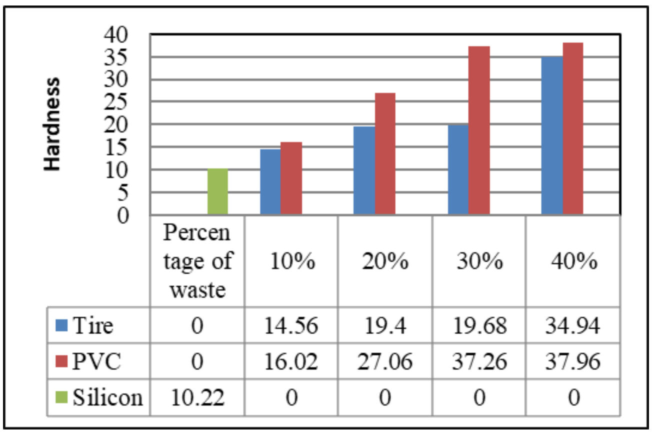


Figure 6. Average hardness shore A

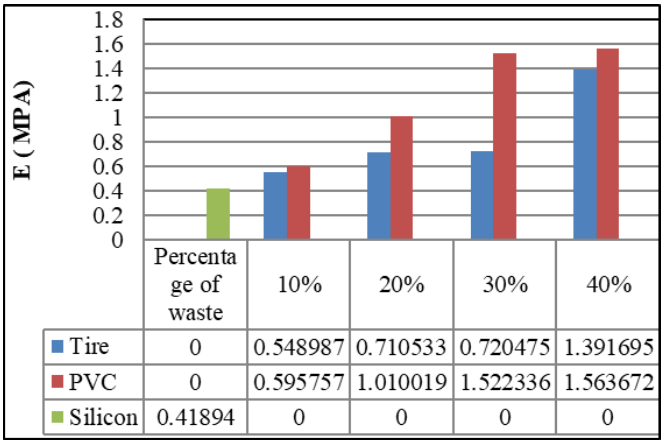


Figure 7. Calculation of elastic modulus E

Figure 7 is a bar graph that displays the calculated values of the elastic modulus E for three materials tire, PVC, and silicon rubber at various percentages of waste (10%, 20%, 30%, and 40%). For Tire, the elastic modulus increases with the percentage of waste, starting from 0.548987 MPa at 10% waste to 1.391695 MPa at 40% waste. PVC exhibits a similar pattern, with the elastic modulus increasing from 0.595757 MPa at 10% waste to 1.563672 MPa at 40% waste. Silicon rubber is only shown to have an Elastic Modulus at 0% waste (0.41894 MPa), with no values presented for higher waste percentages.

A relation between the shore hardness and the Young's modulus for specimens has been derived by Gentand by Mix and Giacomin. Gent's relation has the form:

$$E = \frac{0.0981(56 + 7.62336S)}{0.137505(254 - 2.54s)}$$

where, E is the Young's modulus in MPa and S is the type of shore hardness.

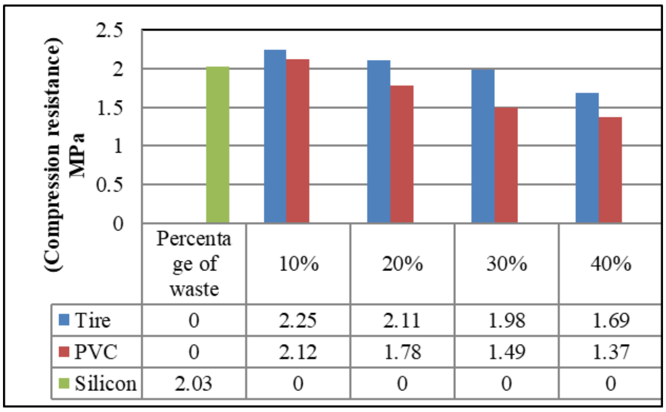
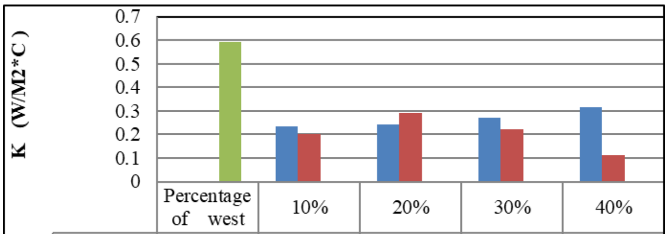


Figure 8. Compression resistance

Figure 8 is a bar graph that illustrates the compression resistance of three materials tire, PVC, and silicon at various percentages of waste (10%, 20%, 30%, and 40%). Tire shows a gradual decrease in compression resistance as the percentage of waste increases, starting at 2.25 MPa with no waste and dropping to 1.69 MPa at 40% waste. PVC also exhibits a decreasing trend, from 2.12 MPa with no waste to 1.37 MPa at 40% waste. Silicon is only represented with a compression resistance value at 0% waste (2.03 MPa) and shows no data for higher waste percentages. This graph demonstrates that the ability of Tire and PVC to resist compression lessens as more waste material is incorporated. Compression resistance is an important material property, especially for structural applications where materials must maintain their shape under compressive forces.



Percentage of west	10%	20%	30%	40%
TIRE 0	0.233	0.243	0.269	0.317
PVC 0	0.2	0.29	0.222	0.111
SILICON 0.592	0	0	0	0

Figure 9. Thermal conductivity coefficient K

Figure 9 is a bar graph that illustrates the thermal conductivity coefficient, denoted as K, for three materials—Tire, PVC, and Silicon—at various percentages of waste. The thermal conductivity coefficient is measured in Watts per meter Kelvin (W/m.K), which quantifies how well a material conducts heat. For Tire, the thermal conductivity coefficient increases as the percentage of waste increases, starting from 0.233 W/m.K at 10% waste and reaching 0.317 W/m.K at 40% waste. PVC shows an increase in thermal conductivity from 0.2 W/m.K at 10% waste to 0.29 W/m.K at 20% waste, but then it decreases to 0.111 W/m.K at 40% waste. Silicon has a high thermal conductivity at 0% waste (0.592 W/m.K), but there are no values for the percentages of waste, indicating that the measurement is not applicable or not measured when waste is added. This graph reveals that the ability of Tire to conduct heat increases with more waste incorporation, the waste material either has higher thermal conductivity or that the combination of waste with the tire material enhances heat transfer. For PVC, the initial increase followed by a decrease that the effects of waste addition on thermal conductivity possibly influenced by the type of waste, the amount added, or changes in the composition or structure of the material.

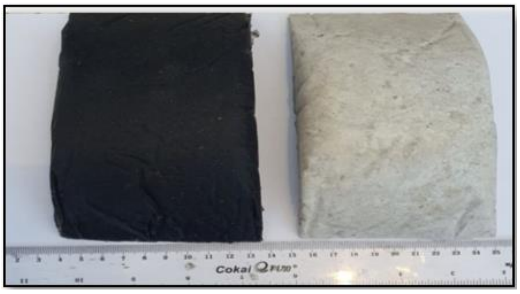


Figure 10. The final models for bumps

Figure 10 shows two physical models side by side, with a ruler for scale. These models are referred to as "the final models for bumps," which may be prototypes or test models for some form of speed bumps or other traffic calming devices. The model on the left is black, which is characteristic of materials that include rubber, such as tires. Considering the context provided by the earlier images and data tables, it is possible that this model is made from recycled tire material. Its dark color is typical of tire-derived products due to the presence of carbon black, a common reinforcing agent in tire manufacturing. The model on the right is white or light gray, which could be indicative of a material like PVC or a composite that includes a significant amount of white or light-colored filler. The creation of such models is often a final step in the material development process, allowing for the evaluation of the materials' properties in a form that is close to the intended final product. These prototypes might be tested for durability, effectiveness in slowing vehicles, weather resistance, or other relevant properties that would be necessary for their application in real-world conditions.

4. CONCLUSIONS

The study comprehensively analyzes the impact of waste percentages on the mechanical and thermal properties of three waste materials; Tire, PVC, and silicon rubber. Hardness increases significantly for Tire, from 14.56 at 10% waste to 34.94 at 40%, and for PVC, from 16.02 to 37.96 within the same range. Simultaneously, the Elastic Modulus for Tire climbs from 0.548987 MPa to 1.391695 MPa, and for PVC, it ascends from 0.595757 MPa to 1.563672 MPa, both at 40% waste. Conversely, compression resistance for both Tire and PVC demonstrates a decline with escalating waste percentages, indicating decreased resistance to compression. Thermal conductivity coefficient (K) unveils a noteworthy increase in Tire, ascending from 0.233 W/m.K to 0.317 W/m.K, while PVC exhibits a more intricate pattern, initially peaking at 0.29 W/m.K and subsequently dropping to 0.111 W/m.K at 40% waste.

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NOMENCLATURE

A area, m^2
d diameter, m
E Young's modulus, MPa
K thermal conductivity, $W.m^{-1}. K^{-1}$
T temperature, °C
t thickness, mm