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Effect of infill parameters in 3D printing and brake pads pattern on the strength of thermoplastic polyurethane material as a substitute for bicycle brake pads

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ABSTRACT

This research is motivated by the increasing utilization of 3D print technology across various sectors. Understanding the appropriate materials is crucial for the effective application of this technology. The aim of this study is to analyse the utilization of Thermoplastic Polyurethane (TPU) material through 3D print as a replacement for bicycle brake pads. The research method involves comparing the strength and durability of TPU material through tensile and wear tests, based on different brake pad patterns, infill geometries, and infill densities in 3D print. The patterns used are derived from two conventional brake pad designs, namely the straight-pattern and the V-pattern. The infill geometries utilized are concentric, gyroid, and zigzag, with infill densities of 25%, 50%, 75%, and 100%. The tensile test results indicate that the gyroid infill geometry for the straight pattern exhibits high strength, while the concentric infill geometry for the V pattern demonstrates high strength. TPU material is found to be 3-4 times stronger than conventional brake pads. However, the wear test results show minimal difference between TPU material and conventional brake pads, but the resistance caused by TPU material is greater. Based on the post-wear test analysis of TPU brake pad shapes, the straight pattern displays better durability in retaining its shape. Both materials possess their own strengths and weaknesses, highlighting the need for further research and improvement to ensure the feasibility of this development.

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1. INTRODUCTION

In the current era of technological advancement, the utilization of 3D printing technology has become widespread across various sectors [1]. 3D printing technology falls under the concept of Additive Manufacturing. Additive manufacturing is the process of converting digital files into 3D solid objects based on the arrangement of material layers. Unlike conventional construction processes, 3D printed buildings are extruded with layers of nozzles without the need for formwork [2,3]. It spans from creating prototypes to manufacturing objects of actual size. In this research, 3D printing technology is harnessed to develop bicycle brake pad products [4]. Bicycle brake pads are crucial components of bicycles, serving the essential function of reducing speed by absorbing kinetic energy through mechanical mechanisms.

The focus of this study lies on the type of bicycle brake known as rim brakes, which operate through friction between the rubber brake pad and the bicycle rim. In this context, the conventional rubber-based bicycle brake pads are substituted with Thermoplastic Polyurethane (TPU) material using 3D printing technology. Thermoplastic Polyurethane material can easily be procured through e-commerce platforms or 3D printing supply stores, as it is a commonly used material in 3D printing. The selection of Thermoplastic Polyurethane material is attributed to its elastic properties akin to rubber [5]. The objectives of this research encompass studying the viability of utilizing Thermoplastic Polyurethane as a substitute for conventional bicycle brake pad materials. Additionally, the research seeks to investigate the influence of the brake pad pattern design and analyse the tensile strength and wear resistance values for various geometric shapes and 3D printing densities. The research involves conducting both tensile strength and wear resistance tests using designs similar to those of conventional brake pads for comparative analysis.

2. METHOD

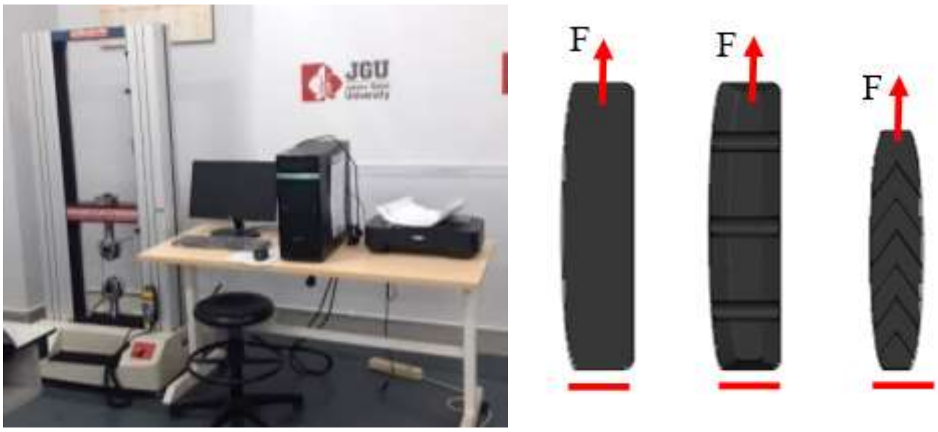
The research method employed is direct tensile testing and wear testing on bicycle brake pad products made of Thermoplastic Polyurethane material. In this research, a literature review was conducted to search for relevant theoretical references related to the existing issue. Additionally, an experimental method was employed, involving direct observation of the research subject. The process began with the design phase, where a design resembling the conventional brake pads commonly sold in bicycle repair shops was created. This design was then modified by cutting it, allowing for a direct comparison between the brake pad made from Thermoplastic Polyurethane material and the brake pad made from rubber material. TPU is a type of thermoplastic polymer as one of the filament materials for FDM (Fused Deposition Modelling) manufacturing. TPU has high elasticity and flexibility [6].

Figure 1. Thermoplastic Polyurethane 3D print filament.

After the design phase, the next step involved the 3D printing process using Thermoplastic Polyurethane filament. The chosen infill geometries were concentric, gyroid, and zig-zag, while the infill densities selected were 25%, 50%, 75%, and 100%. The concentric, gyroid, and zig-zag infill geometry shapes were used because they are the strongest geometry shapes from previous research [7].

Figure 2. Geometric infill shape.

After the 3D printing process is completed, tensile and wear tests are conducted on the bicycle brake pad products. The tensile test is performed using a Universal Testing Machine (UTM), where the product is subjected to tensile force until it fractures. The tensile test results provide information about the mechanical characteristics of a material before it experiences failure.



(a) (b)

Figure 3. (a) Utilized universal tensile machine, and (b) pull direction.

Wear testing, in general, refers to the gradual loss of material or the removal of a certain amount of material from a surface due to the relative movement of one surface against another. The purpose of wear testing is to measure the durability or resistance of a material to abrasion or erosion. In this case, wear testing is conducted on bicycle rims (wheels) that are rotated using a motor at a speed of 1500 rpm while applying a load of 1500 grams. The testing duration is 5 minutes.

Figure 4. wear test equipment and wear test direction

This testing aims to study the durability of Thermoplastic Polyurethane material as bicycle brake pads with commonly used pattern shapes as well as the geometrical form and density employed. The test results of conventional brake pads will be compared with Thermoplastic Polyurethane brake pads to determine whether Thermoplastic Polyurethane material can serve as an alternative to rubber.

3. RESULTS AND DISCUSSIONS

3.1. Tensile test results

The results of the tensile testing conducted on rubber and Thermoplastic Polyurethane brake materials can be seen in Table 1. From the test results, it is evident that Thermoplastic Polyurethane material has a strength that is 3 to 5 times stronger than conventional rubber material, which has values of 0.418 MPa for the straight pattern and 0.209 MPa for the V pattern. The highest tensile strength was obtained in the Giroid geometry with 100% density, with a value of 2.334 MPa for the straight pattern and 1.095 MPa for the V pattern.

Table 1. Tensile test results of original brake pads.

No	Material and Pattern Shape	Tensile strength (MPa)
1.	Brake pad with straight pattern	0,418
2.	Brake pad with V pattern	0,209

Table 2. Tensile test results of thermoplastic polyurethane substitutes material with various pattern.

Sample No	Infill density	Tensile strength (MPa)	
		Straight pattern	V pattern
1	Concentric 25%	1,215	1,005
2	Concentric 50%	1,149	0,841
3	Concentric 75%	1,171	0,992
4	Concentric 100%	2,299	1,052
5	Gyroid 25%	1,403	0,748
6	Gyroid 50%	1,739	0,837
7	Gyroid 75%	1,776	0,905
8	Gyroid 100%	2,334	1,095
9	Zig-zag 25%	1,098	0,690
10	Zig-zag 50%	1,325	0,757
11	Zig-zag 75%	1,444	0,789
12	Zig-zag 100%	2,192	1,074

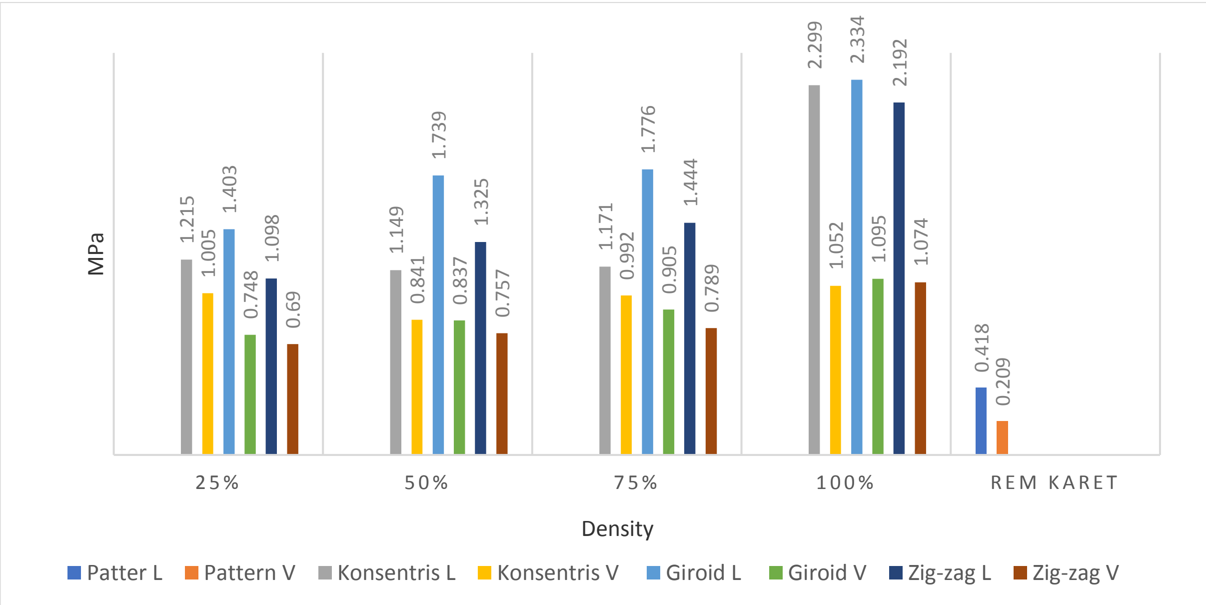


Figure 5. Comparison of tensile test results.

The tensile test results indicate that Thermoplastic Polyurethane material is stronger and more durable, even at lower densities, making it a viable replacement for rubber in brake applications. Additionally, based on the pattern shape, brake pads with patterned shapes exhibit stronger durability compared to the V-shaped pattern.

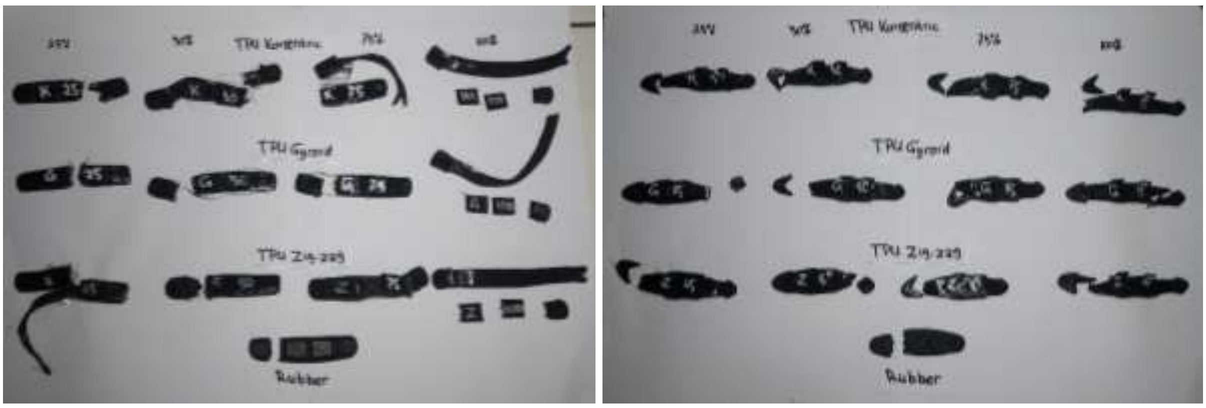


Figure 6. TPU brakes after tensile testing.

Figure 6. depicts the shape of the TPU brake pad after undergoing the tensile test. In the image, it can be observed that the TPU brake pad does not undergo an immediate and direct fracture like rubber brake pads. Instead, the TPU brake pad experiences elongation over a considerable length before eventually fracturing gradually. This phenomenon is attributed to the layered structure of the brake pad mold, which prevents immediate and direct fracture during the tensile test. And the fractures that occur in each brake pad inevitably happen at their respective grooves.

3.2. Wear test results

The wear test conducted for 5 minutes with a rotational speed of 1500 rpm and a load of 1500 grams yielded some differences in the data. The difference in wear test results between rubber and Thermoplastic Polyurethane materials is not significantly distinct. However, there is a noticeable difference in the resistance speed generated between rubber and TPU brake pads. Brake pads made of rubber exhibit very low resistance, resulting in a speed reduction from the initial 1500 to 1136 rpm for the straight pattern and 1145 rpm for the V pattern. In contrast, Thermoplastic Polyurethane material shows a significant resistance, with an average speed reduction from the initial 1500 rpm ranging between 500-700 rpm.

Table 3. Wear test results of original brake pads.

No	Density	V_0 (rpm)	V_1 (rpm)
1	Brake pad with straight pattern	1500	1136
2	Brake pad with V pattern	1500	1145

Table 4 Wear test results of thermoplastic polyurethane substitutes material with various pattern.

No	Density	V_0 (rpm)	V_1 (rpm)	
			Straight pattern	V pattern
1	Concentric 25%	1500	581	651
2	Concentric 50%	1500	690	655
3	Concentric 75%	1500	528	583
4	Concentric 100%	1500	641	719
5	Gyroid 25%	1500	599	671
6	Gyroid 50%	1500	543	617
7	Gyroid 75%	1500	637	645
8	Gyroid 100%	1500	723	591
9	Zig-zag 25%	1500	627	658
10	Zig-zag 50%	1500	607	602
11	Zig-zag 75%	1500	726	676
12	Zig-zag 100%	1500	645	604

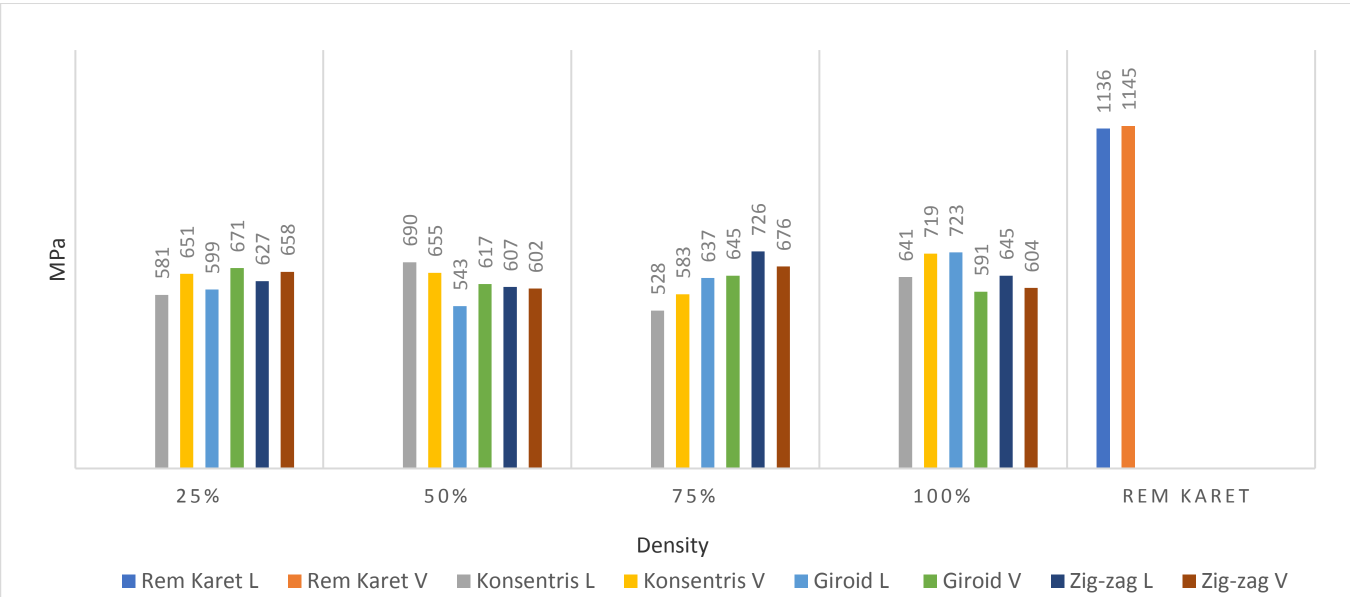


Figure 7. Comparison of wear test results.

Indeed, based on the wear test results, the significant resistance speed exhibited by TPU brake material contributes to its superior braking effectiveness when compared to rubber brake material.

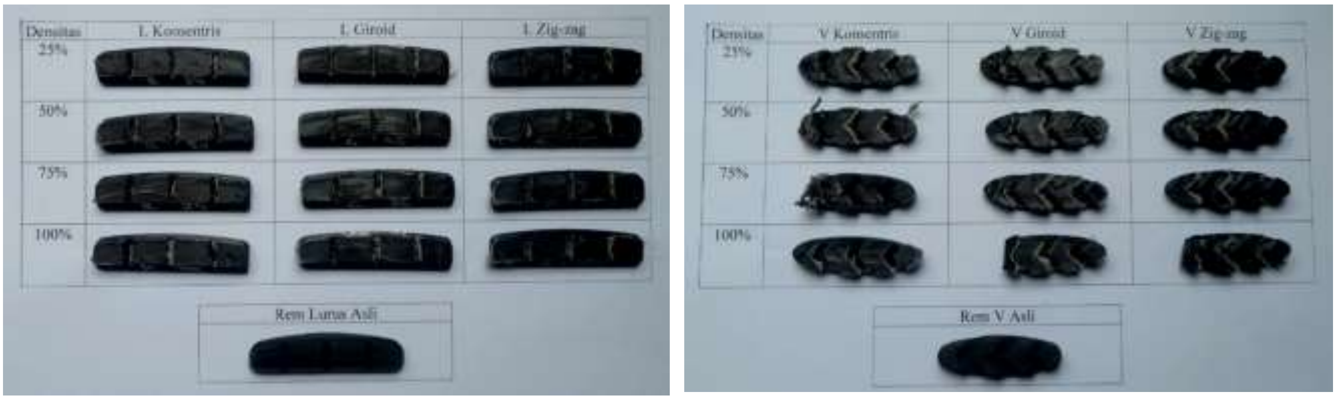


Figure 8. TPU brakes after wear testing

Figure 8 displays the shape of the brake pads after the wear test. In the image, the brake pad with a straight pattern still appears intact, with surface wear observed but without significant changes in its shape. However, in the V-shaped pattern, there is noticeable deformation and extreme wear. This indicates that the straight pattern exhibits better wear resistance compared to the V-shaped pattern.

4. CONCLUSION

Based on the analysis of the two conducted tests, it can be concluded that brake pads with a straight pattern exhibit stronger and better wear resistance compared to brake pads with a V-shaped pattern. Brake pads made of Thermoplastic Polyurethane (TPU) with a straight pattern can be used similarly to conventional rubber brake pads, although they produce greater resistance than conventional rubber brake pads. Both materials have their own advantages and disadvantages. In the development of this product, further research and improvement are needed to assess and ensure the feasibility of this development. A deeper understanding of the mechanical characteristics and performance of TPU brake pads in various usage conditions will be crucial in optimizing the design and use of this material as an alternative to conventional rubber brakes.

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