

Comparative Study of Tribological Parameters of 3D Printed ABS and PLA Materials



Keshav Raheja, Ashu Jain, Chayan Sharma, Ramakant Rana, and Roop Lal

Abstract Rapid prototyping today is observed into practice and is being recognized as a significant technology for design. It demonstrates the process of design situated between conceptual design and real-world construction. It is used to automatically construct physical models from computer-aided design data or is a group of technique used to quickly fabricate a scale model of a physical part or assembly using three-dimensional computer-aided design data. The “three-dimensional printers allow designers to quickly create tangible prototypes of their designs rather than two-dimensional pictures”. The 3D printer used works on fused deposition modelling (FDM) in which two materials are used to make 3D models out of the design made on CAD software. The two materials used are polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS). The model of a pin will be formed using these two materials using various parameters. These parameters are—layer thickness, infill type, infill density and raster angle. In total, we will have then six parameters which include 3D printing parameters and the two materials. Using these five parameters, design of experiments will be created using the software Minitab. Various combinations will be created in the DOE with these six parameters. The pin will be then tested on the pin-on-disc machine which will help us to tell the wear rate and the coefficient of friction of the material through graphs. These graphs will help us decide the combination of parameters which have the most and the weak durability and thus can be used to create the parts we want to create for various industries. This way a comparative study of the tribological test between the two materials will be created.

Keywords 3D · PLA · ABS · DOE · Taguchi

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1 Introduction

3D printing or additive manufacturing is a process of creating a print in which each layer is laid down on the previous layers to make the final product. Hideo Kodama of Nayoga Municipal Industrial Research Institute is generally regarded to have printed the first solid object from a digital design. However, the credit for the first 3D printer generally goes to Charles Hull, who in 1984 designed it while working for the company he founded, 3D Systems Corp. Charles a Hull was a pioneer of the solid imaging process known as stereolithography and the stereolithographic (STL) file format which is still the most widely used format used today in 3D printing [1–3]. He is also regarded to have started commercial rapid prototyping that was concurrent with his development of 3D printing [4]. He initially used photopolymers heated by ultraviolet light to achieve the melting and solidification effect. Since 1984, when the first 3D printer was designed and realized by Charles W. Hull from 3D Systems Corp., the technology has evolved and these machines have become more and more useful, while their price points lowered, thus becoming more affordable [5].

Nowadays, rapid prototyping has a wide range of applications in various fields of human activity: research, engineering, medical industry, military, construction, architecture, fashion, education, the computer industry and many others. For example, for the jewellery sector, 3D printing has proved to be particularly disruptive. There is a great deal of interest and uptake based on how 3D printing can, and will, contribute to the further development of this industry [6]. From new design freedoms enabled by 3D CAD and 3D printing, through improving traditional processes for jewellery production all the way to direct 3D printed production eliminating many of the traditional steps. Also, to support new product development for the medical and dental industries, the technologies are also utilized to make patterns for the downstream metal casting of dental crowns and in the manufacture of tools over which plastic is being vacuum formed to make dental aligners. Architectural models have long been a staple application of 3D printing processes, for producing accurate demonstration models of an architect's vision. 3D printing offers a relatively fast, easy and economically viable method of producing detailed models directly from 3D CAD [7].

Minitab, the software used for creating design of experiments (DOE) is a statistical analysis software which allows the user to focus more on the analysis of data and the interpretation of results. Tribometer used to test the experiments is an instrument which measures tribological quantities, such as coefficient of friction, frictional force and wear volume, between two surfaces in contact [8–10].

There are many advantages of using 3D printing such as saving money and time in production, giving feedback of the product with less wastage, personalized items can be made, innovative ideas can be created, and the most important advantage is that once a prototype fails, it can be created again and again in less time and with less wastage [1–14].

2 Experimentation

The experimentation in this paper consists of doing tribological test on various 3D printed pins which are formed using a combination between different parameters with the help of Minitab software. These pins are then tested on pin-on-disc machine to find out their wear and coefficient of friction with respect to time.

2.1 3D Printer

The 3D printer used in making of these pins was Ender-3 by Creality, shown in Figs. 1 and 2. This 3D printer uses the fused deposition modelling (FDM) technique, shown in Fig. 3, to print the 3D product. In this technique, the model is produced by extruding small beads of material which harden to form layers. A thermoplastic filament or wire that is wound into a coil is unwinding to supply material to an extrusion nozzle head. The nozzle head heats the material up to the certain temperature and turns the flow on and off. Typically, the stepper motors are employed to move the extrusion head in the z-direction and adjust the flow according to the requirements.

The head can be moved in both horizontal and vertical directions, and control of the mechanism is done by a computer-aided manufacturing (CAM) software package running on a microcontroller [15–17]. The cylindrical pin is created in the 3D printing software according to the specifications required by the pin-on-disc machine and according to the combinations of the parameters. These pins are then run through

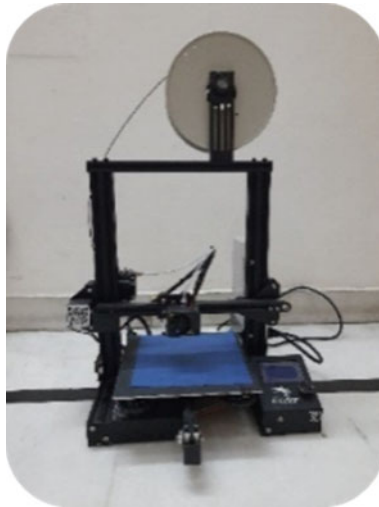


Fig. 1 Photographic image of the 3D printer (Ender-3 by Creality)

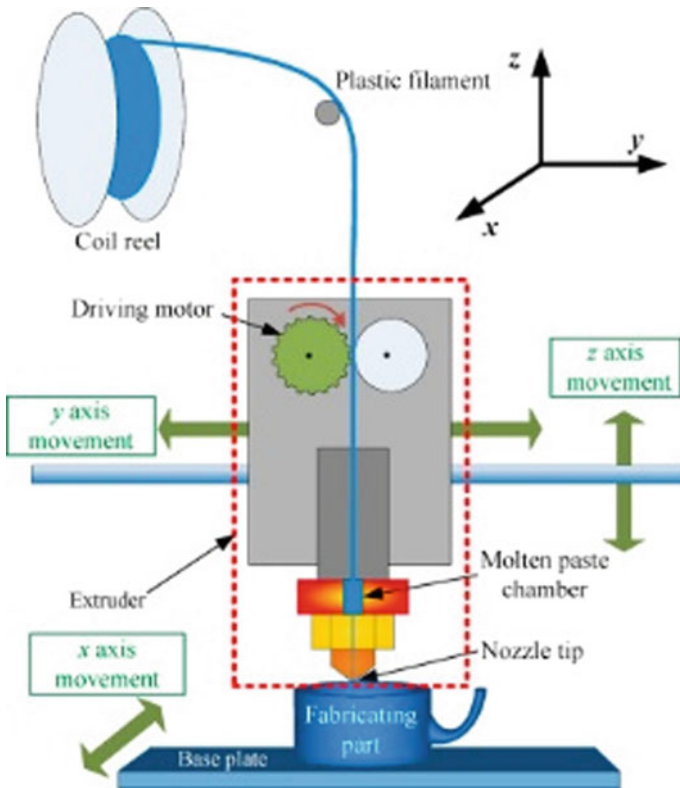


Fig. 2 Schematic representation of 3D printer

slicer which divided the model into the number of layers in which it will be formed. It is then fed to the 3D printer for the printing process.

2.2 Pin-On-Disc Machine and Tribological Test

The tribological tests were conducted by using pin-on-disc tribometer by following the ASTM G99 standard. The 3D printed pins were attached on top of the rotating disc [18]. Now the tribological tests are done on the 3D printed pins to find out the wear and coefficient of friction between the pins and the rotating disc with respect to time. The wear rate is calculated by comparing the wear volume before and after the test. The coefficient of friction is calculated by the ratio of frictional force to the loading force on the pin. The image of pin-on-disc machine is as shown in Fig. 3 [19].



Fig. 3 Pin-on-disc test rig

2.3 3D Printing Parameters

The following parameters were used in building of the 3D printed pins which determines the strength of the pins:

2.3.1 Infill Type

Infill type in a 3D print tells us the internal structure of the 3D print. This internal structure plays an important part in determining the strength of the 3D print. Figure 4a–d. shows several infill types' images that are available in the slice settings.

2.3.2 Fill Density

Infill density is the amount of filament printed inside the object, and this directly relates to the strength, weight and printing duration of the print. Figure 5a–d shows CAD images of infill density.

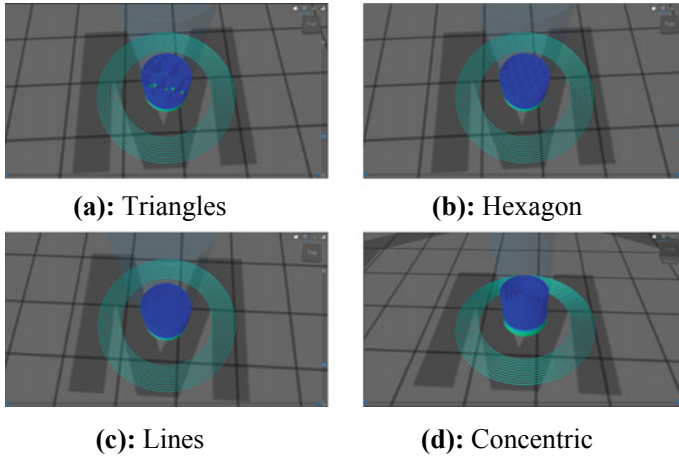


Fig. 4 a–d CAD images of various infill types

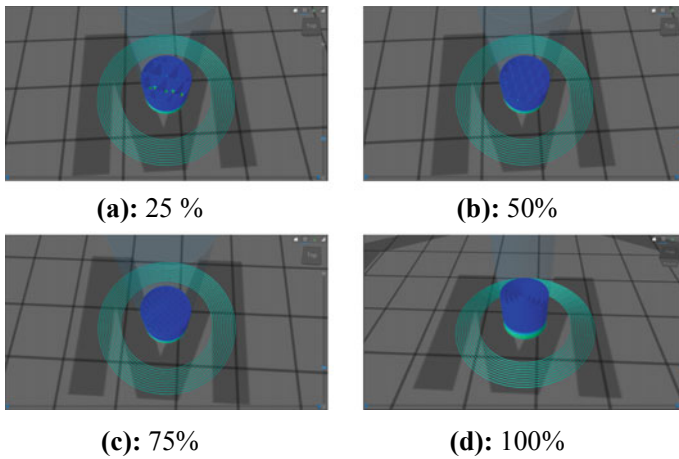


Fig. 5 a–d Cad images of fill density

2.3.3 Layer Thickness

Layer thickness in 3D printing is a measure of the layer height of each successive addition of material in the additive manufacturing or 3D printing process in which layers are stacked. The printing time required and the results of a smoother surface are also greatly determined by layer height. Layer thickness of 0.2 and 0.3 mm is used in the experiment. Figure 6a, b shows the CAD images of the used layer thickness.

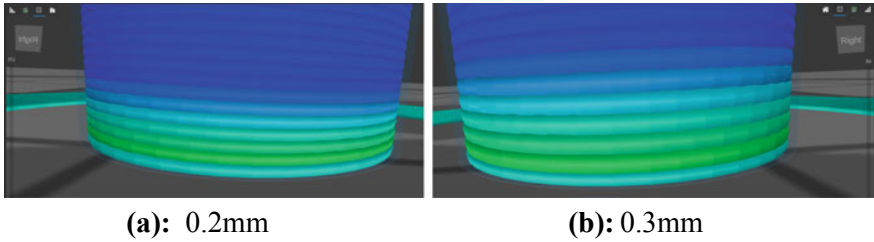


Fig. 6 a, b Cad images of layer thickness

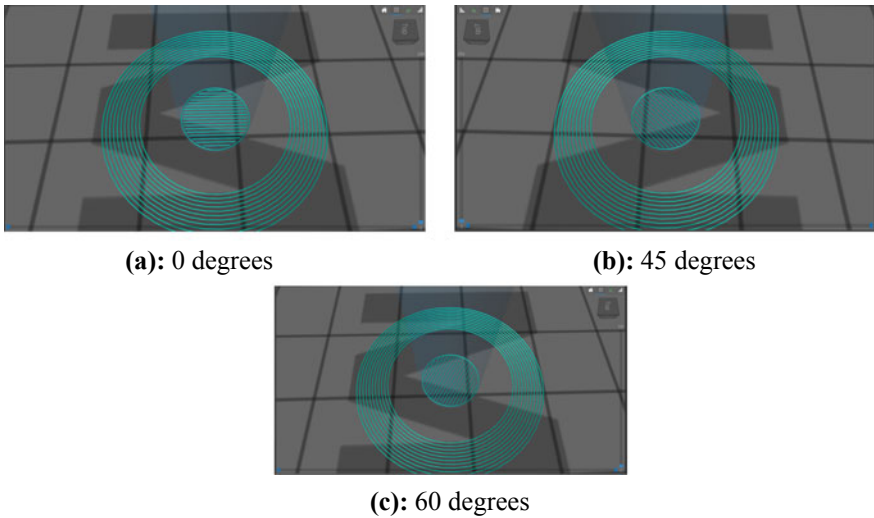


Fig. 7 a–c CAD images of raster angle

2.3.4 Raster Angle

Raster angle in the slicer sets the orientation of the first infill with respect to the heat bed. It determines the strength of the print at the end surface. Figure 7a–c shows the CAD images of raster angle.

2.3.5 Materials

There will be two types of materials which will be used in this experiment.

1. **Polylactic Acid (PLA):** Polylactic acid (PLA) (is derived from corn and is biodegradable) is another well-spread material among 3D printing enthusiasts. It is a biodegradable thermoplastic that is derived from renewable resources. As a result, PLA materials are more environmentally friendly among other plastic

materials. The structure of PLA is harder than the one of ABS, and material melts at 180–220 °C which is lower than ABS. PLA glass transition temperature is between 60 and 65 °C.

2. **Acrylonitrile Butadiene Styrene (ABS):** ABS is one of the most widely used materials since the inception of 3D printing. This material is very durable, slightly flexible and lightweight and can be easily extruded, which makes it perfect for 3D printing. It requires less force to extrude than when using PLA, which is another popular 3D filament. Its glass transition temperature is about 105 °C, and temperature about 210–250 °C is usually used for printing with ABS materials.

2.4 Design of Experiments

Minitab software was used to form a DOE in which we feed the different parameters and the number of experiments we want to perform. In this Taguchi orthogonal array design is used to make combinations in the parameters. The same DOE formed by Minitab is shown in Table 1 [20]. L16(4**2 2**3), Factors:5, Runs:16.

3 Results and Discussions

After experimenting sixteen cylindrical pins on the tribometer, the following are the results. These results consist of the effects on the disc due to experimentation and the plot of wear and coefficient of friction with respect to time.

3.1 Disc Wear

Due to the friction between the two contact surfaces, i.e. the rotating disc and the stationary loaded pin, there is wear on the disc at different track diameters. Figure 8 is the image of the disc after the experiments [14] (Table 1 and Fig. 9).

3.2 Wear on Pins

The following are the images and the graphs showing the occurrence of wear on the sixteen cylindrical pins during the experiments (Fig. 10).



Fig. 8 Wear tracks developed on discs

Table 1 Design of Experiment (DOE) showing the average values of wear obtained in all the 16 experiments performed.

S. No.	Fill density	Infill type	Material	Layer thickness	Rester angle	Avg. wear
1	25	Triangle	PLA	0.2	45	13.41
2	25	Hexagon	PLA	0.2	45	118.13
3	25	Conc	ABS	0.3	60	71.95
4	25	Line	ABS	0.3	60	7.44
5	50	Triangle	PLA	0.3	60	8.66
6	50	Hexagon	PLA	0.3	60	5.26
7	50	Conc	ABS	0.2	45	7.52
8	50	Line	ABS	0.2	45	13.21
9	75	Triangle	ABS	0.2	60	5.26
10	75	Hexagon	ABS	0.2	60	4.96
11	75	Conc	PLA	0.3	45	2.59
12	75	Line	PLA	0.3	45	6.96
13	100	Triangle	ABS	0.3	45	5.73
14	100	Hexagon	ABS	0.3	45	8.08
15	100	Conc	PLA	0.2	60	4.37
16	100	Line	PLA	0.2	60	8.79

3.2.1 Images of Wear on Pins

See Fig. 11.

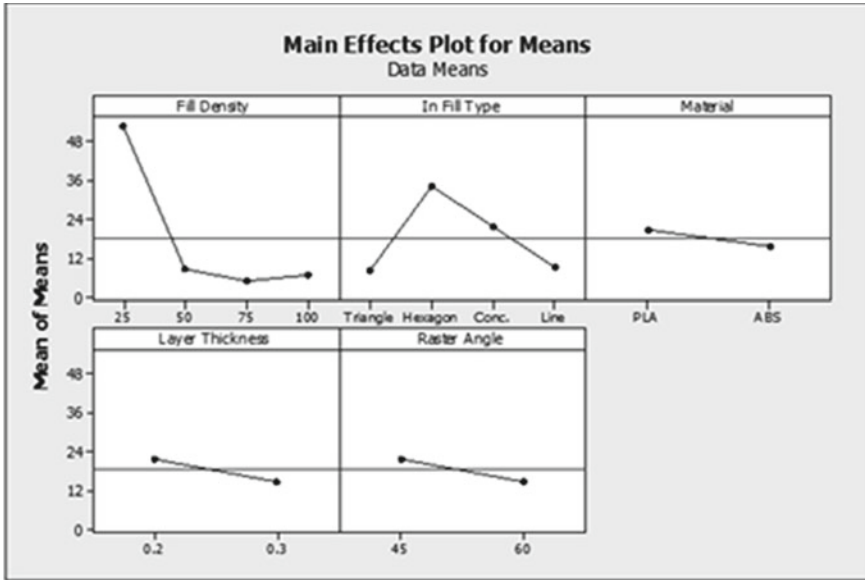


Fig. 9 Variation of wear with fill density, infill type, material, layer thickness and raster angle

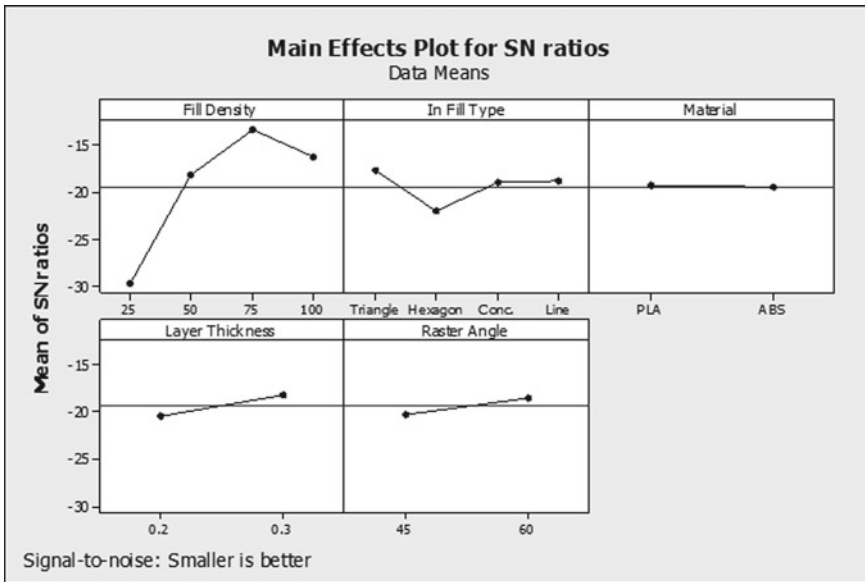


Fig. 10 Variation of SN ratio of wear with fill density, infill type, material, layer thickness and raster angle

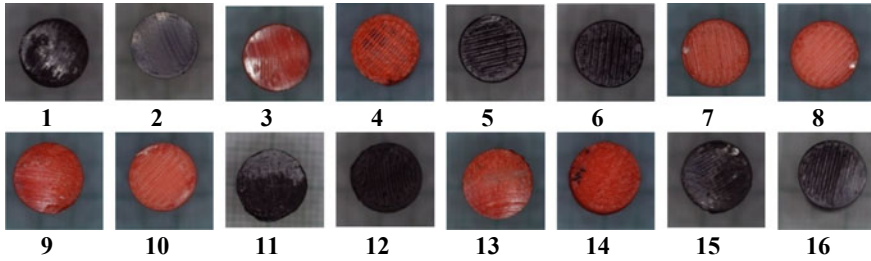


Fig. 11 Microscopic images of wear of all the 3D printed pins used in experimentation

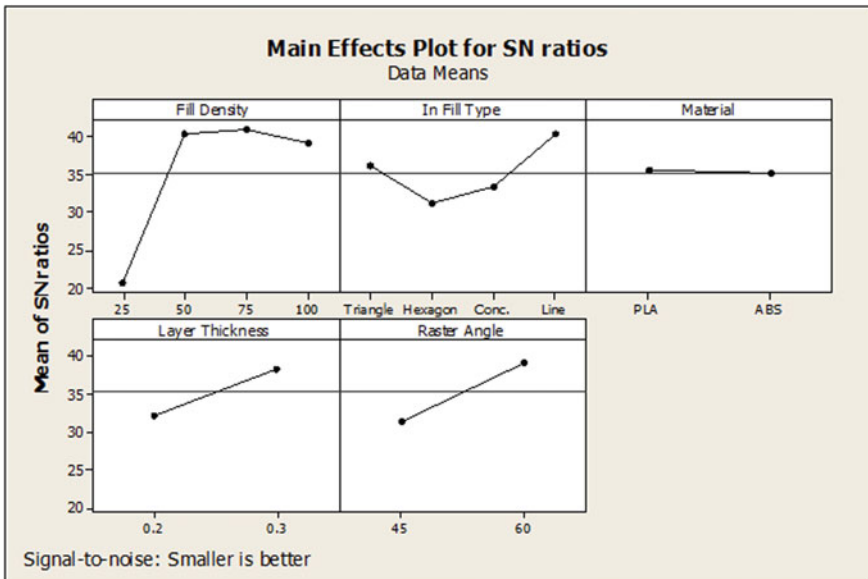


Fig. 12 Variation of SN ratio of coefficient of friction with fill density, infill type, material, layer thickness and raster angle

3.3 Coefficient of Friction

See Figs. 12 and 13.

4 Conclusions

The material undergoes wear due to sticking of the surfaces as a result of heat generated from friction. Wear test of material ABS and PLA with steel wear was

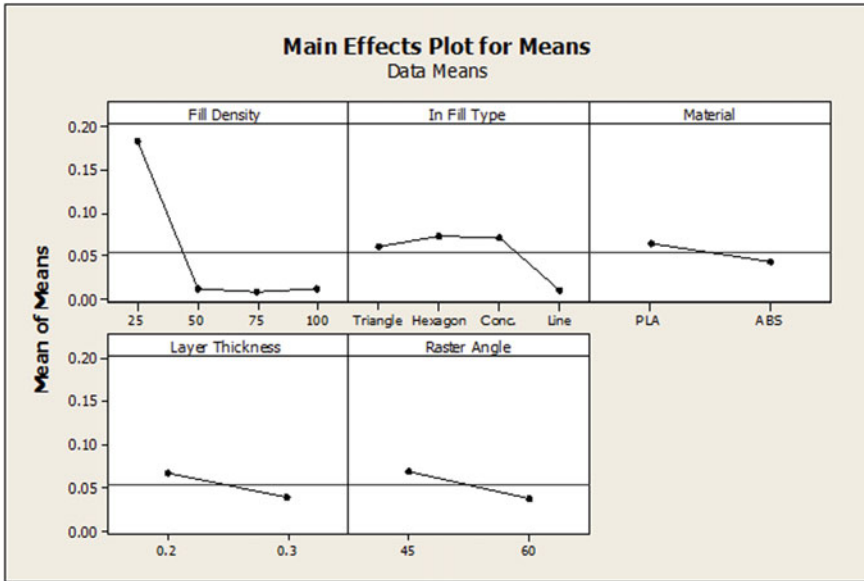


Fig. 13 Variation of coefficient of friction with fill density, infill type, material, layer thickness and raster angle

carried out. Taguchi optimization technique has been applied for optimizing the wear and coefficient of friction to investigate the influence of parameters like fill density, infill type, material, layer thickness and raster angle. The results are as follows:

1. Medium fill density produces lowest wear as well as coefficient of friction.
2. Line type of infill produces the lowest wear as well as coefficient of friction. So, this means hexagonal infill types produce highest wear as well as coefficient of friction.
3. In comparison to PLA, ABS produces less wear and coefficient of friction with respect to steel.
4. Higher layer thickness produces lower the wear and coefficient of friction.
5. Same way, higher raster angle produces lower the wear and coefficient of friction.

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