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Study of deflection behavior of 3D printed leaf springs

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Abstract. The authors developed a research for studying the behaviour of 3D printed machine elements such as: clutches, springs, bellows, screws, nuts, gears, differential and planetary mechanisms. There are different applications where metallic springs cannot be used: corrosive, explosive, magnetic field, electromagnetic radiation, nuclear techniques and other applications or environments that require light spring masses.

1. Introduction

First question is: does this spring have a linear characteristic? The dependence between actuating force and spring deflection has to be linear. The study took into account different printing parameters: material, fill factor, dimensions, rigidity of the parts. This paper deal with study of behaviour concerning leaf springs (planar springs) considering two representative shapes: rectangular and triangular. Also there were considered three different materials: PLA, ABS and MetalFil Classic Copper. All these springs were printed for four thicknesses: 2,5; 3; 3,5; 4 mm.

Theoretical description of the spring deflection is listed below. In figure 1 is presented the rectangular leaf spring actuated with force P. The spring dimensions are: length - l, width - b and thickness - h [1]. The deflection f is:

$$f = \frac{P \cdot l^3}{3 \cdot E \cdot I} = 4 \cdot \frac{P \cdot l^3}{E \cdot b \cdot h^3} \quad (1)$$

where E is Young modulus and I is moment of inertia. There were considered l=90 mm; b=12 mm.

In figure 2 is presented the triangular leaf spring actuated with force P. The spring dimensions are: length - l, width - b at the triangle base and thickness - h. For triangular leaf spring, the deflection will be:

$$f = \frac{6 \cdot P \cdot l^3}{E \cdot b \cdot h^3} \quad (2)$$

There were considered l=70 mm; b=50 mm [1].



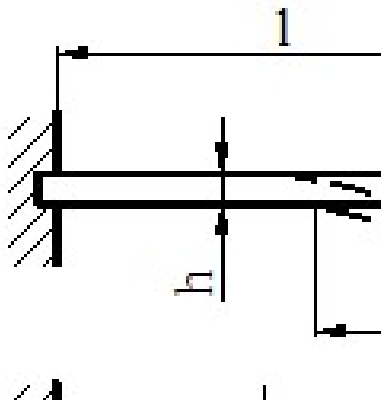


Figure 1. Rectangular leaf spring actuated with force P

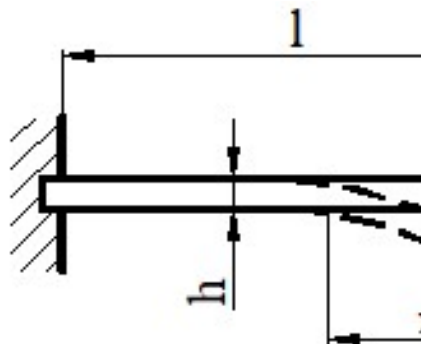


Figure 2. Triangular leaf spring actuated with force P

2. Technical description

Processes based on material extrusion use a thread of different qualities of material that heats up to a temperature a few degrees below the melting temperature, after which it reduces its diameter to 0.2 mm by extruding it into a depositing device, device that moves in the XOY plane to materialize a section of the virtual model. This manufacturing process is based on heating the material to be deposited near its melting point and then depositing this melted material where it is needed to build the desired pattern.

The process comprises three main steps: pre-processing step, building step and post processing step. In the first pre-processing phase, the first step is to load the CAD model of the piece into the Quick Slice program (program that generates the FDM machine code), followed by space orientation of the piece so that the piece construction is optimal in terms of working time and material consumption. This orientation is achieved with the help of specialized functions (rotation, translation, mirroring, etc.). After the CAD model is oriented, it's sectioning with the working plane of the machine (horizontal planes), which results in several sets of level curves called perimeters. The sectioning step (along the Z-axis) is chosen depending on the type of material used and the diameter of the melt extrusion nozzle. In all cases shown in the article nozzles with a diameter of 0.4 mm were used. When all the paths that the extruder has to follow are generated, the operation that completes the pre-processing step is saving the information in a command file [2, 3].

Since the design phase for the rectangle and triangle models, it has been taken into account that the orientation of the workpiece during the manufacturing process leads to a reduction in manufacturing time so that its minimum size is oriented along the Z axis, the filling rate for all the studied cases being 20%.[4]

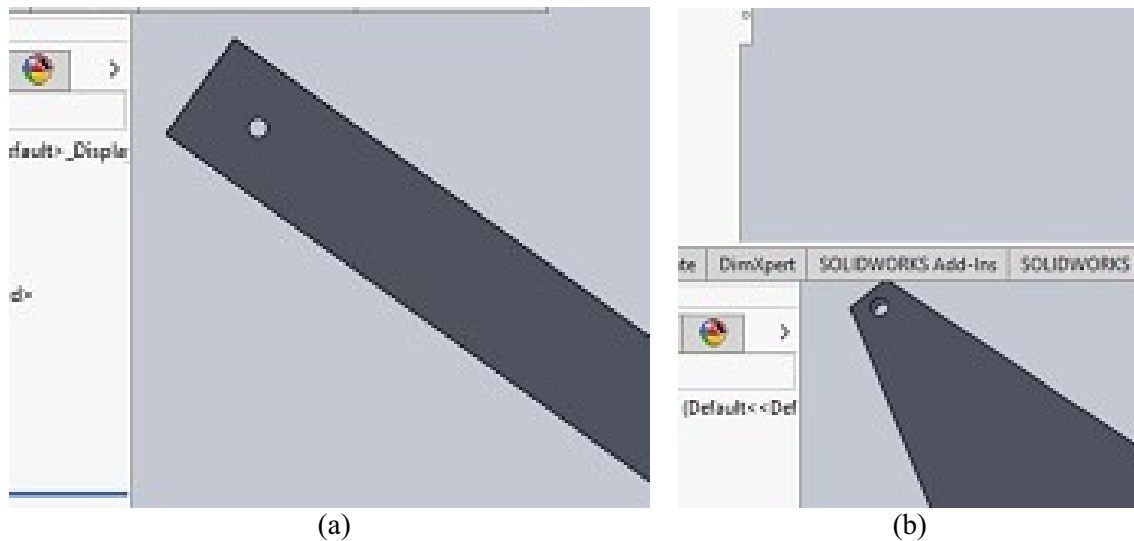


Figure 3. Designed 3D models: a) rectangular leaf spring; b) triangular leaf spring

Among the thermoplastic materials (solid plastics that become malleable by heating and hard by cooling) used by FDM technology - Fused Deposit Modeling, the set of test pieces presented in the article is realized from the following types: PLA (polylactide), ABS (Butadiene styrene acrylonitrile) and MetalFil Classic Copper (PLA + Copper) which is a PLA-based filament and contains about 80% copper metal powders.

PLA - plastic obtained by processing plants like corn, sugar beet, potatoes, sweet smell, no hazardous components, considered environmentally friendly and can come into contact with food. Stronger and more rigid than ABS, the PLA is more complicated to use in assembling parts that require joining. And the deformation property at temperatures lower than ABS (about 65 °C) prevents its use in engineering projects. It is intended for objects that will be stored under normal temperature conditions. Used most often for various containers in the food industry.

ABS - a highly versatile polymer used in many industries and exhibiting a variety of properties. In 3D printing, the ABS is a tough plastic, high temperature resistant (it begins to deform at about 100°C) and with a slight flexibility (compared to the PLA) which helps to achieve the objects that require joining. It is soluble in acetone – with a brush soaked in acetone, the surfaces can be easily finished becoming shiny and the various parts of an object can stick together. Contains in its composition oil. In large dimensions there is a risk of deformation [5].

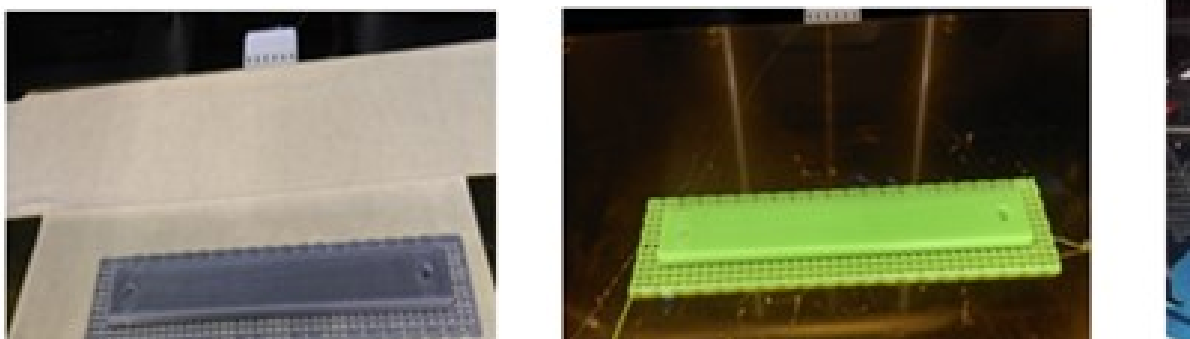


Figure 4. Rectangular test models for the three types of materials: PLA, ABS and MetalFil Classic Copper

MetalFil Classic Copper - PLA blend with copper powders can be perfectly printed with nozzles ≥ 0.4 , has a density of 3.4 g / cc, has improved flow behavior and adhesion between layers, allows 3D

FDM technology prints copper objects that are almost identical to genuine copper objects. MetalFil printouts can then be post-processed, without traces and without deformation after cooling, allowing them to create copper objects with various patina effects.

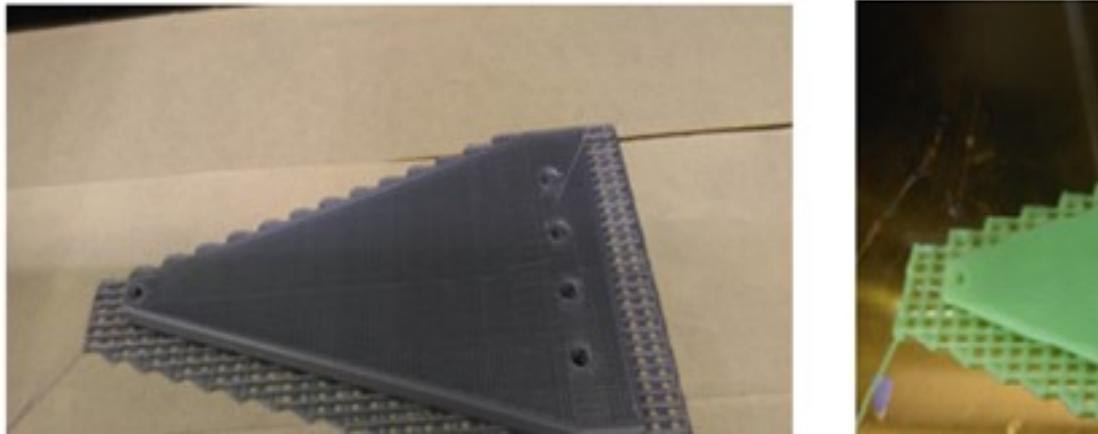


Figure 5. Triangular test models: PLA and ABS

3. Experimental setup

In figure 6 is presented Hans Schmidt experimental setup based on test stand, HV 500 N, which mainly consists of: 1 - deflection measuring system, 2 - Imada force transducer, 3 – 3D -printed spring. Maximum testing force is 500N. The Imada transducer is connected to PC for record the penetration force and time. The testing edge is of a conical shape, with 90° edge angle.



Figure 6. Hans-Schmidt vertical test stand

3.1 Operating mode

All springs were deflected considering the same deflection range : 0...10 mm. The deflection were set using deflection measuring system 1 (figure 6). For these deflection were measured actuation forces, using Imada force transducer 2. In figure 6 is shown the rectangular PLA, ABS and MetalFil Classic Copper spring and the characteristic of triungiular MODEL of ABS .

The experimental results for the three types of PLA, ABS and MetalFil Classic Copper materials realized on a 3D printer with rectangular and triangular shapes with the thicknesses of 2.5 mm, 3 mm, 3.5 mm and 4 mm are shown as graphs in the following figures:

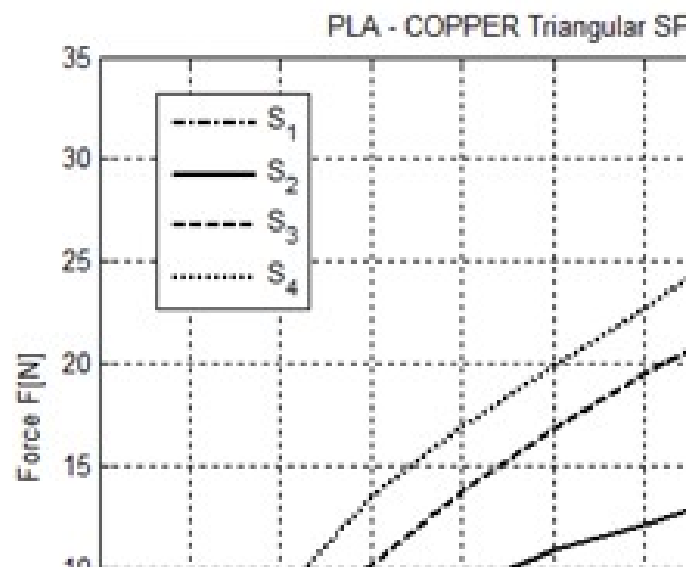


Figure 7. S1 triangular leaf spring with thickness $h=2.5$ mm, S2 triangular leaf spring with thickness $h=3$ mm, S3 triangular leaf spring with thickness $h=3.5$ mm, S4 triangular leaf spring with thickness $h=4$ mm

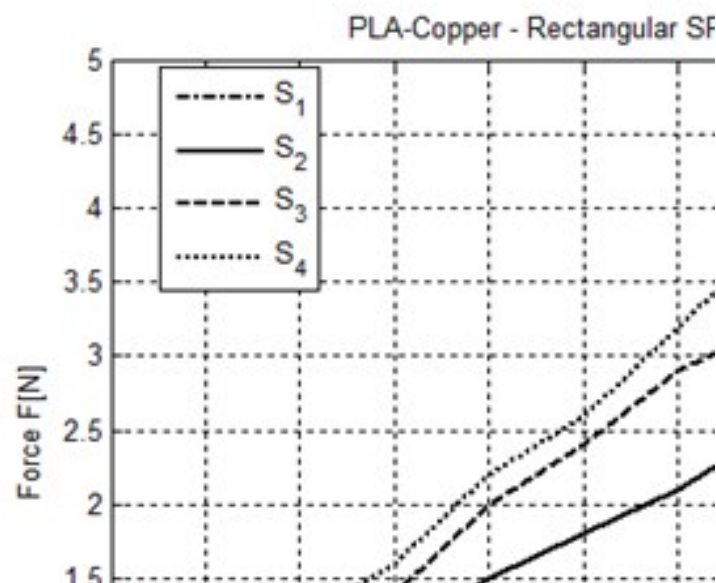


Figure 8. S₁ rectangular leaf spring with thickness $h=2.5$ mm, S₂ rectangular leaf spring with thickness $h=3$ mm, S₃ rectangular leaf spring with thickness $h=3.5$ mm, S₄ rectangular leaf spring with thickness $h=4$ mm

In figure 9 is shown the triangular PLA spring and in figure 10 is the characteristic of rectangular spring using the same material.

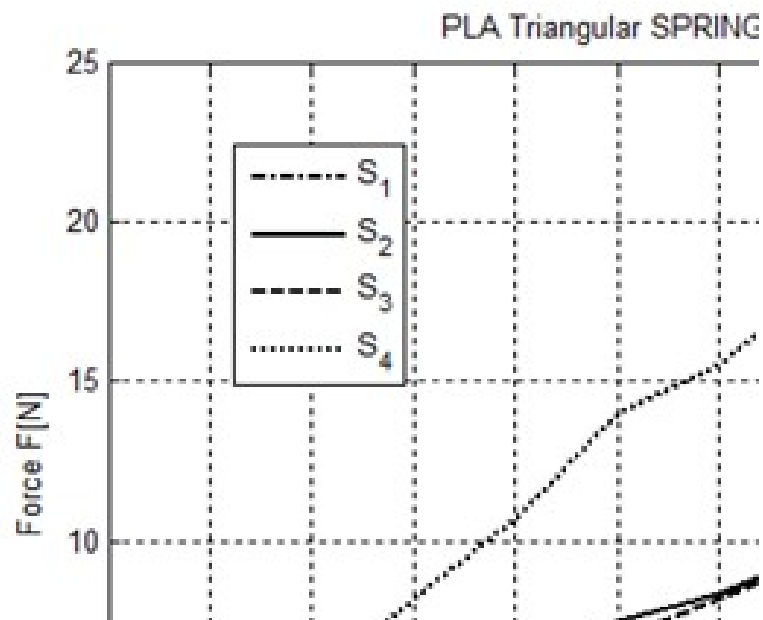


Figure 9. S1 triangular leaf spring with thickness $h=2.5$ mm, S2 triangular leaf spring with thickness $h=3$ mm, S3 triangular leaf spring with thickness $h=3.5$ mm, S4 triangular leaf spring with thickness $h=4$ mm

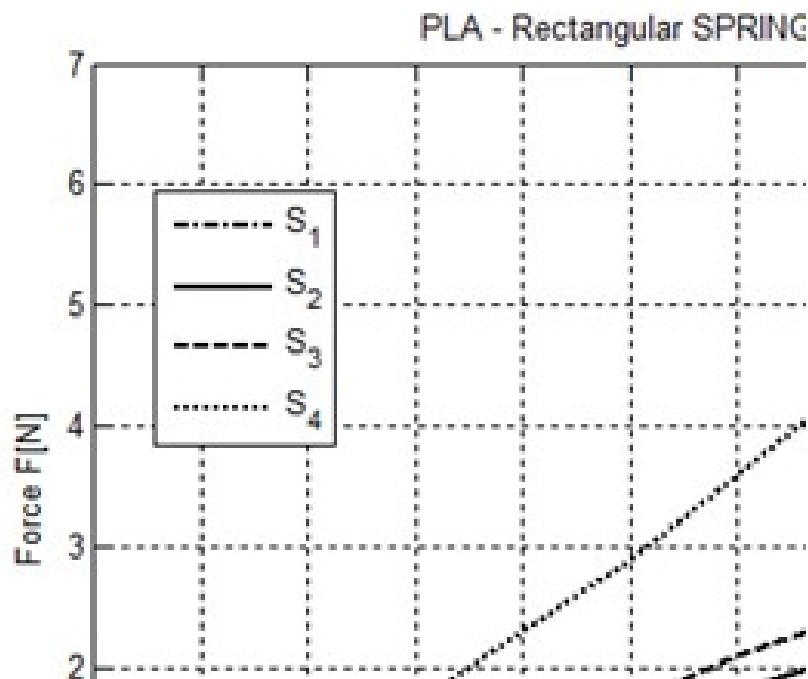


Figure 10. S1 rectangular leaf spring with thickness $h=2.5$ mm, S2 rectangular leaf spring with thickness $h=3$ mm, S3 rectangular leaf spring with thickness $h=3.5$ mm, S4 rectangular leaf spring with thickness $h=4$ mm

Finally, in the figure 11 is shown the triangular ABS spring and in the figure 12 is the characteristic of rectangular spring using the same material.

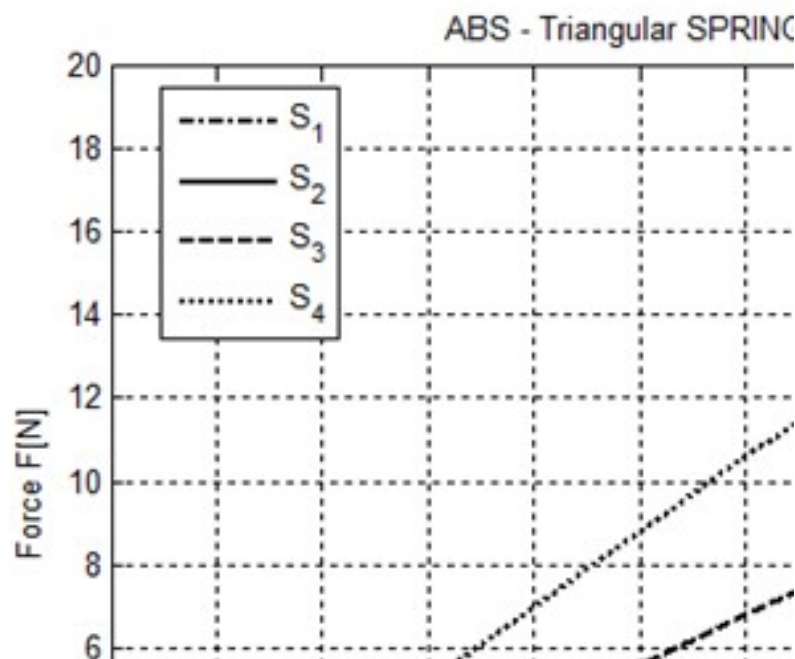


Figure 11. S1 triangular leaf spring with thickness $h=2.5$ mm, S2 triangular leaf spring with thickness $h=3$ mm, S3 triangular leaf spring with thickness $h=3.5$ mm, S4 triangular leaf spring with thickness $h=4$ mm

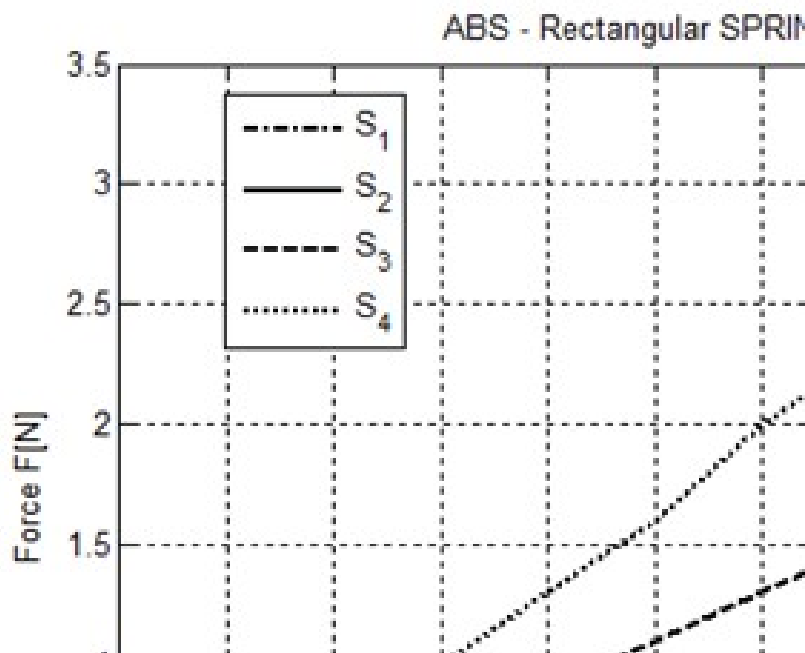


Figure 12. S1 rectangular leaf spring with thickness $h=2.5$ mm, S2 rectangular leaf spring with thickness $h=3$ mm, S3 rectangular leaf spring with thickness $h=3.5$ mm, S4 rectangular leaf spring with thickness $h=4$ mm

Using equations (1) and (2), there were determined the Young modulus, E , considering experimental data. The results are: $E_{\text{PLA}} = [1,29...1,9] \cdot 10^3 \text{ N/mm}^2$; $E_{\text{MetalFil Classic Copper}} = [2,39...2,78] \cdot 10^3 \text{ N/mm}^2$; $E_{\text{ABS}} = [1,12...1,24] \cdot 10^3 \text{ N/mm}^2$.

Table 1 gives numerical values expressed in grams of investigated leaf springs. To determine the mass of the leaf springs, an electronic weighing having the value of division of 0.001 g was used (Figure 13).



Figure 13. Determining the mass of the triangular MetalFil Copper leaf spring

Table 1. Comparison of mass values of investigated structures

Material	Thickness[mm]	Triangular shape value [g]	Rectangular shape value [g]
ABS	2.5	3.5	2.2
	3	4	2.5
	3.5	4.5	2.8
	4	5	3
PLA	2.5	5.5	3
	3	6	3.2
	3.5	6.5	3.8
	4	7	4
MetalFil Classic Copper	2.5	20	11
	3	23	14
	3.5	25	15
	4	38	18

4. Conclusions

All leaf springs has a linear characteristic , there is a linear dependence between force and deflection. This means that 3D -printed springs could be used as machine elements in different applications as it was mentioned above. For the same material, the triangular springs has a higher rigidity than the

rectangular springs. Considering the same shape and the same thickness ABS springs has a lower rigidity than PLA and MetalFil Classic Copper. The higher Young modulus belongs to MetalFil Classic Copper. Considering the experimental tests as well as the graphical results we can conclude: the ABS leaf spring has the most stable linear behaviour and the MetalFil Classic Copper leaf spring has the largest deflections. Research has also been made on the mass value of each leaf spring according to shape and material, concluding that the most suitable material for engineering projects that take into account the mass of constituent components is ABS compared to the other two investigated materials.

5. References

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