DOI: 10.2507/30th.daaam.proceedings.075

INFLUENCE OF MATERIAL COLOUR ON MECHANICAL PROPERTIES OF PLA MATERIAL IN FDM TECHNOLOGY

Adi Pandzic, Damir Hodzic & Aleksa Milovanovic

This Publication has to be referred as: Pandzic, A[di]; Hodzic, D[amir] & Milovanovic, A[leksa] (2019). Influence of Material Colour on Mechanical Properties of PLA Material in FDM Technology, Proceedings of the 30th DAAAM International Symposium, pp.0555-0561, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-22-8, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/30th.daaam.proceedings.075

Abstract

Today, one of the most used material in FDM (fused deposition modelling) 3D printing technology is PLA (polylactic acid). On market today, there are many different companies that producing PLA material filament for 3D printers with different diameter and colours. Previous research showing that there are so many parameters in FDM technology that affect on mechanical properties of 3D printed material like layer height, infill density, temperature etc. Topic of this article is to investigate whether colour of PLA material effect on material tensile properties and in what amount. It will be tested more than 10 different colours of PLA material, and for every colour it will be tested 3 specimens. Specimens are prepared according to ISO 527-2, and all printed with same 3D printing parameters and with 100% infill. Also, all used materials are of same company and for every colour specimen will be 3D printed from same filament spool. All this is done to avoid other parameters to effect on material properties. The results of this study will be useful for colour selection of the PLA material without compromising the material tensile properties of 3D printed product.

Keywords: Material; Colour; PLA; FDM; 3D Print

1. Introduction

Additive manufacturing (AM) is at the heart of strategic discussions by the European Factories of the Future Research Association (EFFRA) because of its capabilities in personalized parts, high manufacturing flexibility, and resource efficiency. For this reason, development of this type of technology has experienced a great increase since it was introduced in the market, leading to a set of manufacturing process families that are alternative to subtractive manufacturing or formative manufacturing. One of the most widespread processes, due to its versatility and low cost, is fused deposition modelling (FDM). Fused deposition modelling grows almost 20% in profit each year in industries such as automotive or aeronautics. This method generally uses thermoplastic polymers. Despite being one of the most used AM processes, it is not completely industrialized yet. This is due to the large number of parameters that govern the process, as well as the lack of standardization, studies, and communication [1].

Fused deposition modelling is a fast-growing additive technology that is now used both for hobby users and for large manufacturing companies around the world. FDM is additive manufacturing technology that can produce parts with complex geometries by the layering of extruded materials, such as PLA (polylactic acid), ABS (acrylonitrile butadiene styrene), PET (polyethylene terephthalate), nylon and more other different thermoplastics, but also materials reinforced with carbon or glass fibers, metal particles and other.

The first step in production processes with additive technologies is the creation of 3D CAD models in the appropriate modeling software (Solidworks, Catia V5, Inventor, ...), where dimensions, shape and model constraints are given. Next, the process of cutting the layers model into the suitable software, and adjusting the process parameters on the machine that most often work on the principle of adding "layer-by-layer" material. In the world market, a large number of additive technologies have been implemented, which are primarily distinguished by the method of layer construction (photopolymerization, extrusion and solidification, bonding, laminating, etc.) [2].

Fused Deposition Modeling (FDM) is one of the most commonly used AM technologies due to its low cost and easy application. It is an extrusion-based additive technology. In FDM process, a thermoplastic filament is driven to an extruder, where is heated to a semi-liquid state by a heater block and loaded through a hot-end nozzle to a build bed on XY plane. The material is added layer-by-layer in Z axis direction. The movement commands and printing parameters are provided by a G-code file, made with a CAM or slicer program (Fig 1) [3].

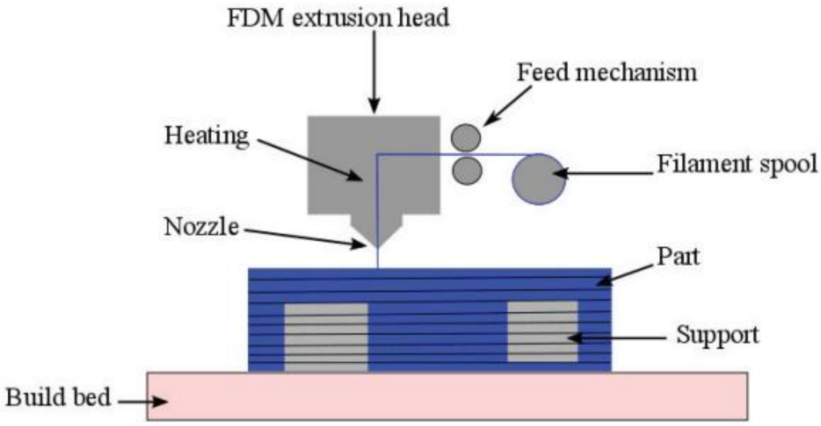

Fig. 1. FDM process schematic [4]

The quality and mechanical characteristics of FDM 3D printed products are the functions of many parameters and factors from the material itself, 3D printing parameters to environment factors. These parameters include basic (before 3D printing) material (filament) characteristics, infill pattern, infill density (filling percentage), build direction, layer height, temperature, nozzle diameter, extrusion width, air gap, build orientation and many other [5], [6], [7], [8], [9].

Currently, there are many different materials available on the market for FDM 3D printing technology including ABS, nylon, polycarbonate, high-density polyethylene, high impact polystyrene, PLA, and others. PLA has emerged as one of the favourites among the FDM 3D printing users. Polylactic acid is a natural polymer, derived from renewable sources such as starch, a large carbohydrate that plants synthesize during photosynthesis. PLA has a relatively low melting point, 150°-160° C, thus requiring less energy to print with the material, which also provides advantages for off-grid applications in the developing world. In addition, PLA has been shown to be a safer alternative to the possibly toxic ABS plastic. Furthermore, PLA is a more printable material and has mechanical properties significantly higher than most other plastics except some kinds of polycarbonate, nylon, and composite blends. However, this plastic is little studied in relation to the FDM process, despite its great potential because it is renewable, compostable, and biocompatible [1], [10].

By reviewing the literature it can be noticed that the greatest accent is given to the influence of parameters on mechanical properties of material. Another characteristic barely evaluated is the influence of different material pigmentations. Today, there are many different colours of PLA material of the same manufacturer, and in most cases it is assumed to have the same mechanical properties regardless of colour. This is one of the reasons why we chose to examine whether and how much the colour of the PLA material influences the mechanical properties of the finished product.

In the further work we will be examined 13 different colours of PLA material of the same manufacturer and their influence on mechanical properties will be investigated.

2. Research objectives and methodology

The aim of this study was to investigate influence of colour PLA material on mechanical properties of finished product. PLA material, ordered from the same company 3D Republika, has been used to manufacture the specimens. Properties of this material given by manufacturer are presented in table 1. Experiment methodology schematic preview is presented in Fig. 2.

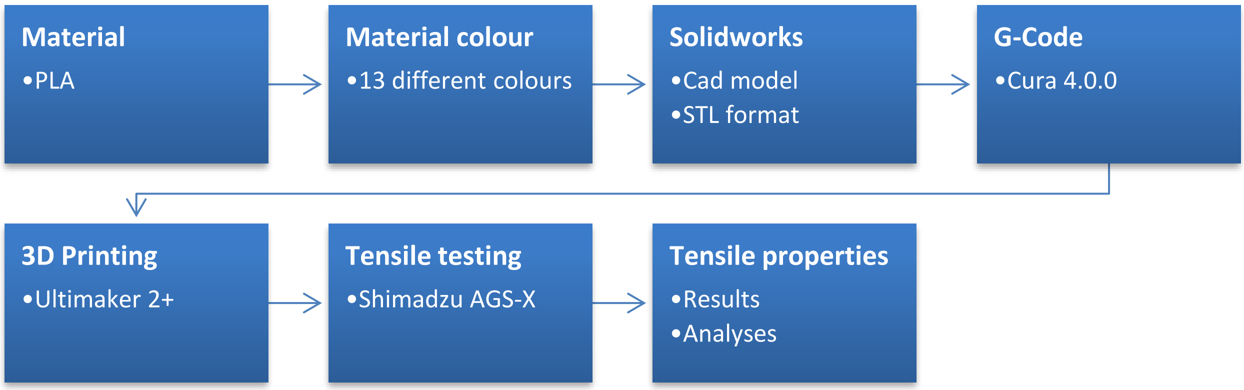

Fig. 2. Experiment methodology

In addition, the manufacturer gives the same characteristics regardless of the selected colour. Diameter of material wire (filament) is 2,85mm, and manufacturer guarantee Ø tolerances ±0,10mm and roundness ≥ 95%. Also, the manufacturer 3D Republika has 33 different types of colours for PLA material.

PLA material properties		
Description	**Test method**	**Typical value**
Filament diameter size	-	2,85 mm
Tensile Strength at Yield (MPa)	ISO 527	70 MPa
Strain at yield	ISO 527	5 %
Strain at break	ISO 527	2 %
E-Modulus	ISO 527	3120 MPa
Impact strength - Charpy method 23˚C	ISO 179	3,4 kJ/m^2
Moisture absorption	ISO 62	1968 ppm
Printing temperature	DF	205 ± 10 °C
Melting temperature	ISO 11357	1155 ± 35 °C
Vicat softening temperature	ISO 306	60 °C
Glass transition temperature	ISO 11357	57 °C

Table 1. PLA material properties by manufacturer

For this experiment we chose 14 different colours of PLA material: green, blue, white, orange, pink (magenta), red, gold, grey, silver, glow in the dark (GD), yellow, black, brown, purple. For each colour 3 different samples were prepared. Specimens are prepared according to ISO 527-2, and technical drawing is presented on Fig. 3. CAD model of specimen and STL format of 3D model are prepared using 3D design tool (software) Solidworks 2019.

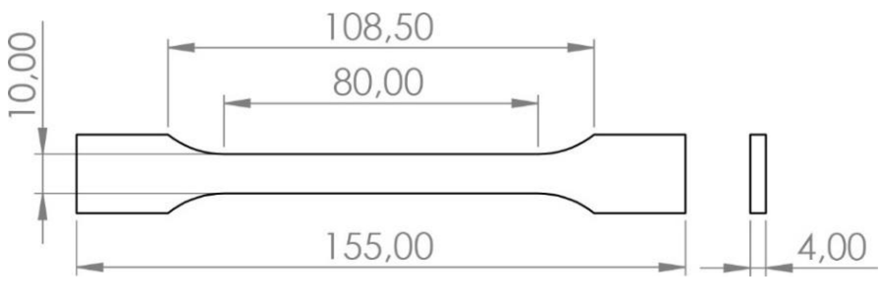

Fig. 3. Test specimen according to ISO 527-2

The test specimens are manufactured on Ultimaker 2+ desktop 3D printer, each specimen was printed under the same conditions, and with 100% infill. G-code is prepared with Ultimakers slicer software “Cura” version 4.0.0. Specimens are printed with “flat” printing orientation and 45˚ raster angle, shown on Fig. 4. Also brim around specimen is used for better adhesion with print bed and to reduce wrapping of material, after 3D printing it is removed from specimen.

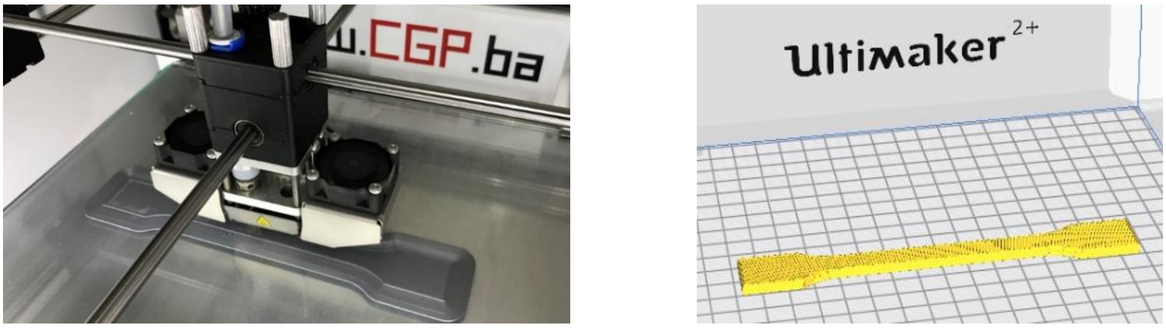

Fig. 4. 3D Printing specimen orientation

Printing parameters are selected using the “normal” print profile from Cura slicer, and main selected printing parameters are presented in table 2. Also Ultimakers 2+ brass nozzle is used with diameter of 0,4 mm.

3D printing parameter	Value
Layer height	0,15 mm
Wall thickness	0,7 mm
Infill density	100 %
Print speed	60 mm/s
Printing temperature	200 ˚C
Build plate temperature	60 ˚C

Table 2. Main selected 3D printing parameters

In total, 42 specimens are 3D printed of PLA material in 14 different colours. Printed samples were then subjected to tensile testing consistent with ISO 527-2 standard.

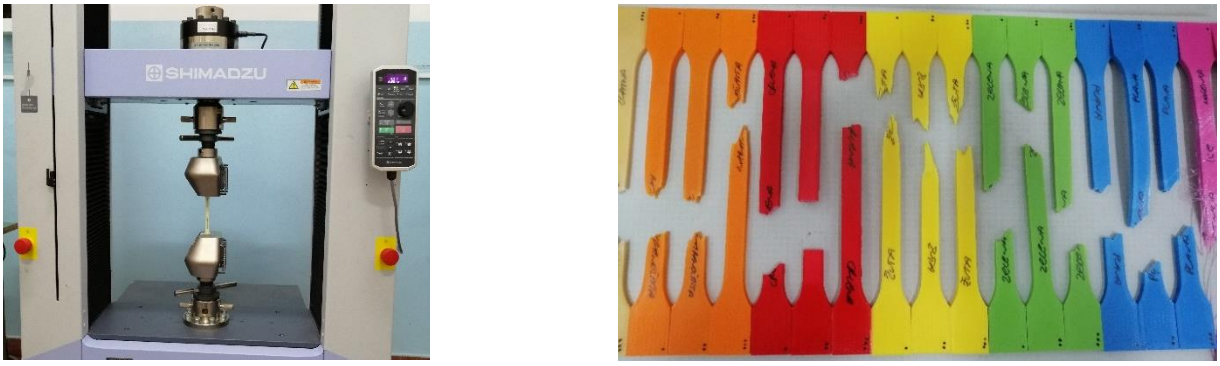

Fig. 5. Tensile testing on Shimadzu AGS-X 100 kN tensile machine and broken specimens after testing

Specimens are tested on Shimadzu AGS-X tensile machine with capacity of 100kN (Fig. 5). This tensile machine is capable of testing specimens at a speed of up to 0,001mm/min, with a measurement accuracy of +/- 0,5N. High sampling rate of 1msec ensures high accuracy of received values.

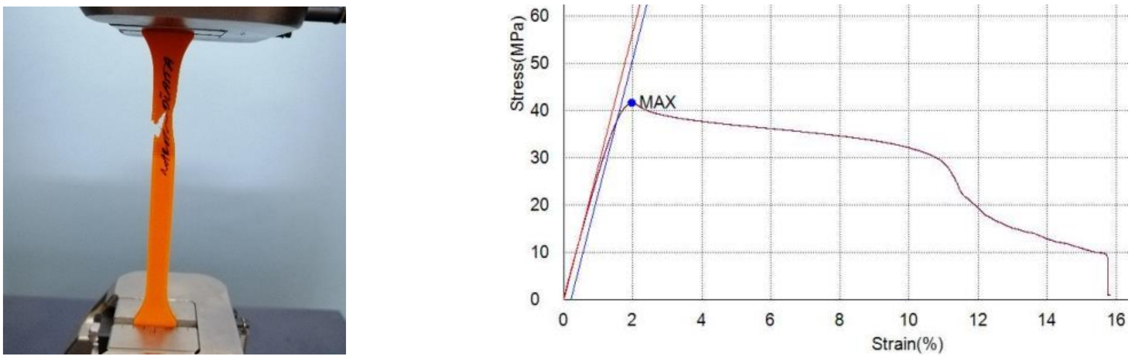

Fig. 6. Tensile testing of orange colour PLA material and results in stress-strain diagram

Tensile testing was performed with testing speed of 1 mm/min. During tensile testing, monitoring and collecting results were performed using "Trapezium-X" (Shimadzu Corp., Kyoto, Japan) software. Also, for every specimen, strain-stress diagram was plotted (Fig. 6.). After testing all printed samples, results are collected and analysed with statistic methods in Excel and presented in further text.

3. Results and discussion

In this experiment, colour influence of PLA material on tensile properties was analysed. During the test, tensile properties as elastic modulus, ultimate tensile strength (UTS), yield strength, toughness and strain were recorded.

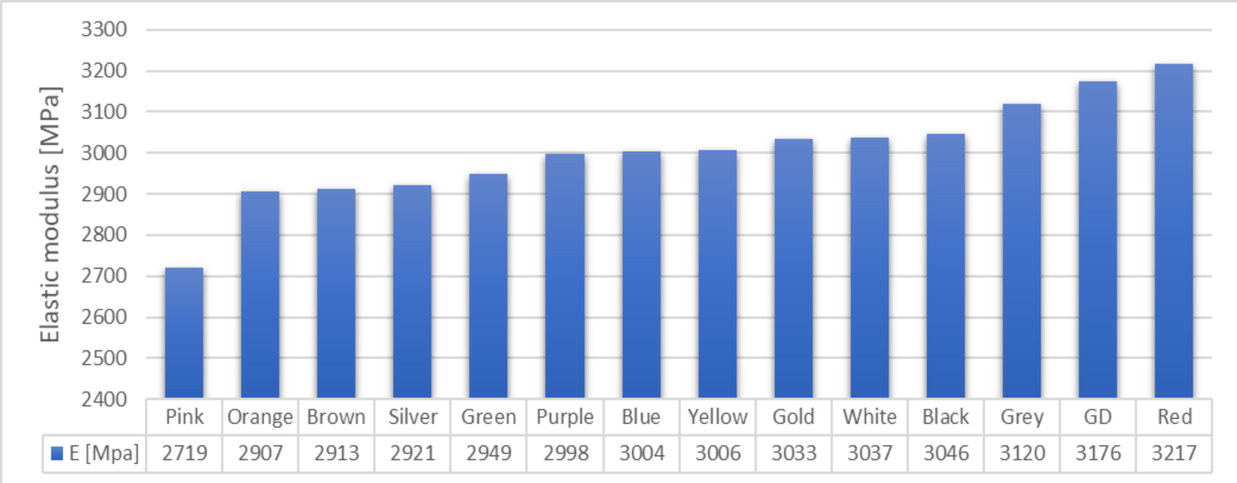

Fig. 7. Influence of PLA material colour on elastic modulus

Colour of PLA material have influence on elastic modulus (Fig. 7.), depending of colour it varies from 2719 MPa up to 3217 MPa. Red colour PLA material gave highest elastic modulus (3217 MPa), and pink colour gave lowest elastic modulus (2719 MPa).

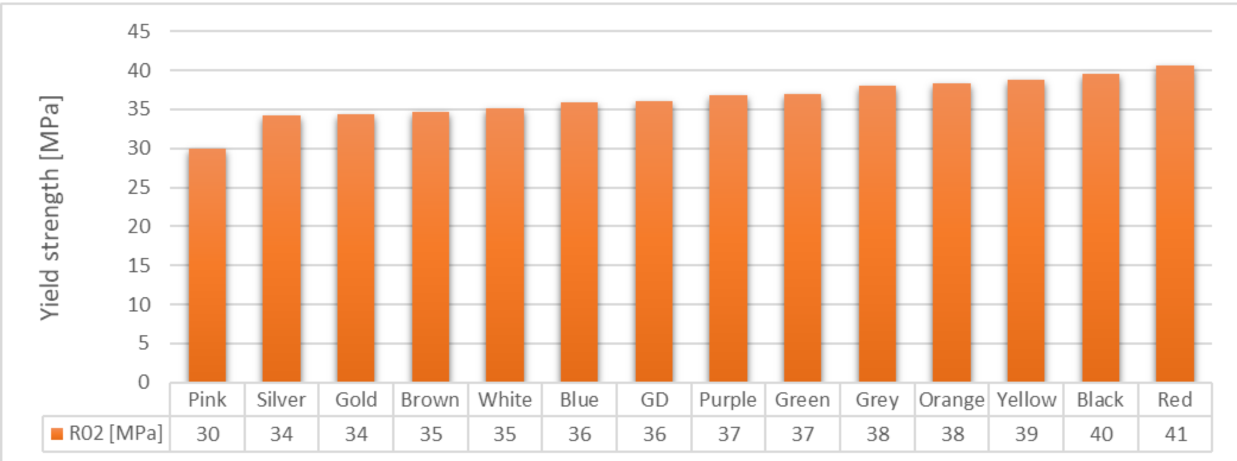

Fig. 8. Influence of PLA material colour on yield strength

Colour of PLA material have influence on yield strength, from diagram above (Fig. 8.) it can be seen that there is no some colour with major impact on yield strength, and it varies from 30 MPa to 41 MPa depending on colour. PLA material with red colour gave highest yield strength of 41 MPa, and pink colour gave lowest yield strength of 30 MPa.

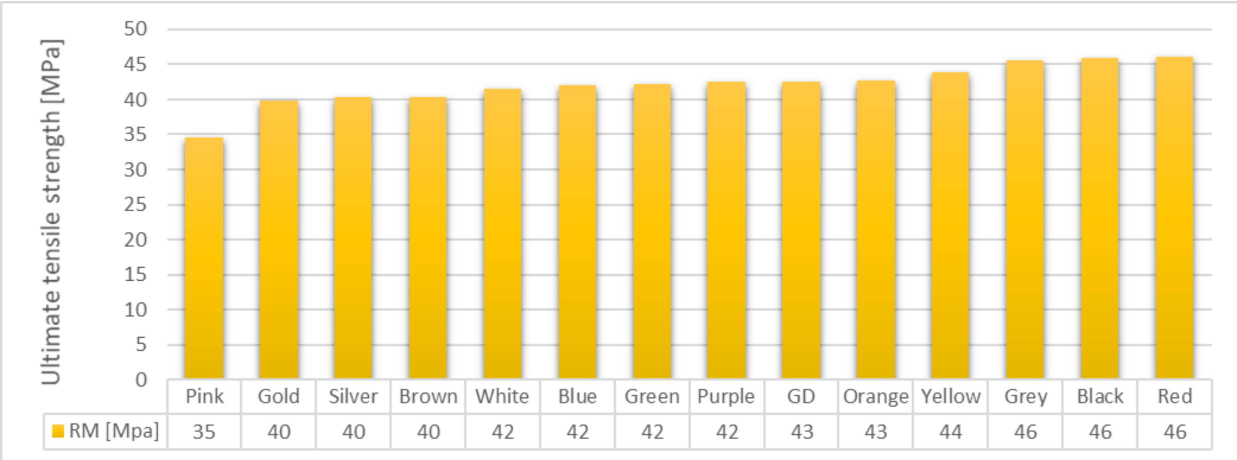

Fig. 9. Influence of PLA material colour on ultimate tensile strength

Colour of PLA material have influence on UTS, from diagram above (Fig. 9.) it can be seen that there is no some colour with major impact on UTS, and it varies from 35 MPa to 46 MPa depending on colour. PLA material with red colour gave highest UTS of 46 MPa, and pink colour gave lowest UTS of 35 MPa.

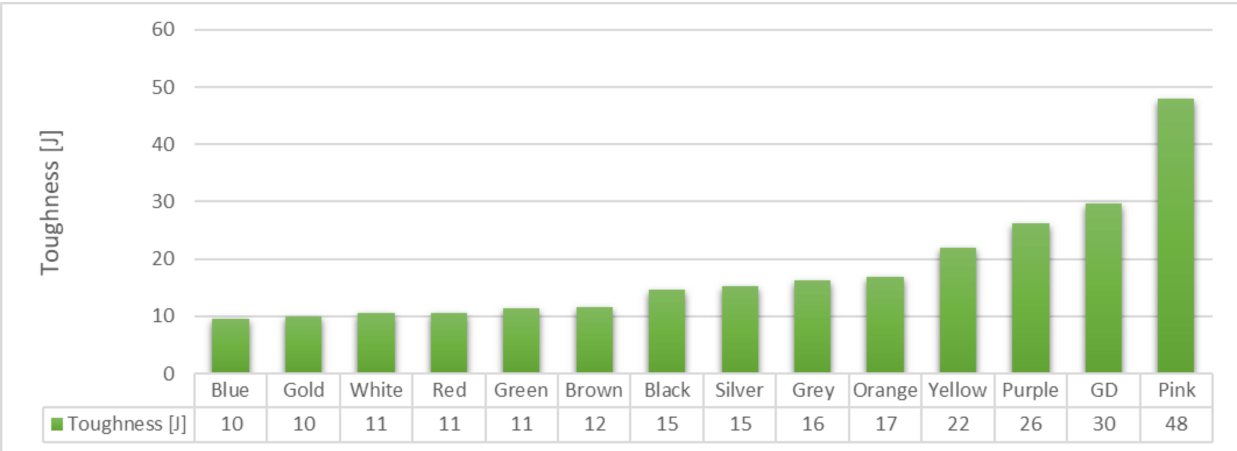

Fig. 10. Influence of PLA material colour on toughness

In this study, toughness is calculated by surface under the stress-strain diagram of every specimen. Colour of PLA material have influence on toughness, from diagram above (Fig. 10.) it can be seen that there is a significant influence of yellow, purple, GD and pink colours on toughness. Analysing all colours from diagram, toughness varies from 10 J up to 48 J. Pink colour gave highest toughness of 48 J, and blue colour gave lowest toughness of 10 J.

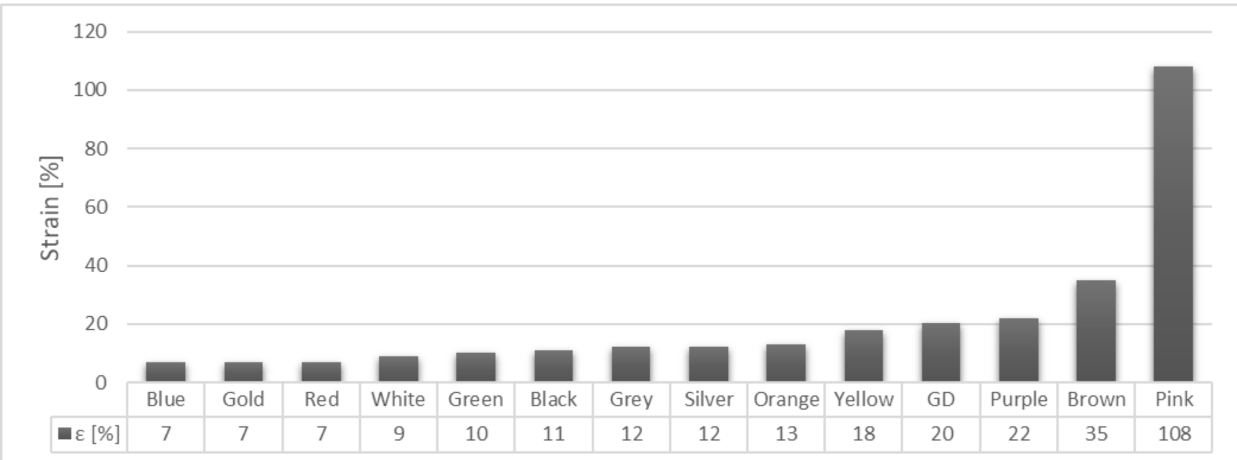

Fig. 11. Influence of PLA material colour on strain

Analysing the strain, its obvious from diagram above (Fig. 11.) that brown and pink colour have highest influence on strain, where brown colour gave strain of 35% and pink up to 108%.

4. Conclusion

Today on market we have many FDM material manufacturers, and analysing properties of the material that they give on the declaration, it can be noticed that for different colours of one same material (in this case PLA) they don't make a difference in mechanical properties. This was one of the reasons of this research, to determine whether the colour influence on mechanical properties (in this case tensile properties) of PLA material.

After testing 14 different colours of PLA material, the following conclusions are reached:

- Colour of PLA material have influence on elastic modulus, and depending of colour it varies up to 18% (from 2719MPa to 3217MPa).
- Colour of PLA material have influence on yield strength, and depending of colour it varies up to 36% (from 30MPa to 41MPa).
- Colour of PLA material have influence on ultimate tensile strength, and depending of colour it varies up to 31% (from 35MPa to 46MPa).
- Colour of PLA material have influence on toughness, and depending of colour it varies over 300% (from 10J to 48J).
- Colour of PLA material have influence on strain, and depending of colour it varies over 400% (from 7% to 108%).

This study analyse only influence of PLA colour on tensile properties. In future research, the influence of material colour on other mechanical properties (bending, hardness, pressure, etc.) should be examined, and also influence of colour on mechanical properties of other materials (ABS, PET, etc.).

5. References

[1] Valerga A. P.; Batista M.; Salguero J. & Girot F. (2018), Influence of PLA Filametn Conditions on Characteristics of FDM Parts, Materials, Vol. 11 (8), 1322, July 2018, DOI: https://doi.org/10.3390/ma11081322

[2] Cekic A.; Begic-Hajdarevic D.; Muhamedagic K. & Guzanovic N. (2018). Experimental Investigations of Process Parameters Influence on Dimensional Accuracy and Mechanical Properties of FDM Manufactured Parts, Proceedings of 29th DAAAM International Symposium on Intelligent Manufacturing and Automation, Zadar, ISSN 1726-9679, ISBN 978-3-902734-20-4, Katalinic B. (Ed.), pp.0210-0214, Published by DAAAM International, Vienna, DOI: 10.2507/29th.daaam.proceedings.030

[3] Pinero Vega D.; Batista Ponce M.; Valerga Pureta A. P.; Vazquez Martinez J. M. & Fernandez Vidal S. P. (2018). A Comparison of Macro and Microgeometrical Properties of Specimens Made With a FDM Commercial Printer and its Opensource Retrofit Version, Proceedings of 29th DAAAM International Symposium on Intelligent Manufacturing and Automation, Zadar, ISSN 1726-9679, ISBN 978-3-902734-20-4, Katalinic B. (Ed.), pp.1108-1115, Published by DAAAM International, Vienna, DOI: 10.2507/29th.daaam.proceedings.158

[4] Alafghani A.; Qattawi A.; Alrawi B. & Guzman A. (2017). Experimental Optimization of Fused Deposition Modelling Processing Parameters: a Design-for-Manufacturing Approach, Available from: https://www.sciencedirect.com/science/article/pii/S2351978917302615 Accessed: 2019-06-06

[5] Jap N. S. F.; Pearce G. M.; Hellier A. K.; Russell N.; Parr W. C. & Walsh W. R. (2019), The Effect of Raster Orientation on the Static and Fatigue Properties of Filament Deposited ABS polymer, International Journal of Fatigue, Vol. 124., July 2019, 328-337, ISSN 0142-1123

[6] Akhoundi B. & Behravesh A. H. (2018), Effect of Filling Pattern on the Tensile and Flexural and Mechanical Properties of FDM 3D Printed Products, Experimental Mechanics an International Journal, Vol. 11340, December 2018, ISSN 0014-4851

[7] Kumar N.; Jain P. K.; Tandon P. & Pandey P. M. (2018), The Effect of Process Parameters on Tensile Behavior of 3D Printed Flexible Parts of Ethylene Vinyl Acetate (EVA), Journal of Manufacturing Processes, Vol. 35, August 2018, 317-326, ISSN 1526-6125

[8] Babagowdam; Kadavera Math R. S.; Goutham R. & Srinivas Prasad K. R. (2017). Study of Effects on Mechanical Properties of PLA Filament Which is Blended With Recycled PLA Materials, Available from: https://iopscience.iop.org/article/10.1088/1757-899X/310/1/012103 Accessed: 2019-08-06

[9] Byberg K. I.; Gebisa A. W. & Lemu H.G. (2018), Mechanical Properties of ULTEM 9085 Material Processed by Fused Deposition Modeling, Polymer Testing, Vol. 72, December 2018, 335-347, DOI: https://doi.org/10.1016/j.polymertesting.2018.10.040

[10] Wittbrodt B. & Pearce J. M. (2015), The Effect of PLA Color on Material Properties of 3-D Printed Components, Additive Manufacturing, Vol. 8, 110-116, October 2015, DOI: https://doi.org/10.1016/j.addma.2015.09.006