Available online at https://www.gyanvihar.org/researchjournals/ctm_journals.php
SGVU International Journal of Convergence of Technology and Management
E-ISSN: 2455-7528
Vol.9 Issue 1 Page No 99-105
Conference Proceedings-TMRI-2023

FDM process parameters influence on the mechanical properties of ABS

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Abstract:

Designing and manufacturing functional parts for industries such as engineering and medicine is a major goal of fused deposition modeling (FDM). These activities must be supported by the knowledge of how the different settings of the process parameters influence the mechanical behavior of the products. However, obtaining this information is a rather complex task given the wide variety of possible combinations of materials - 3D printers - cutting software - process parameters. Hence the importance of reviewing the ongoing research on this topic to identify practical and useful aspects, key parameters and limitations of the process, but also to understand to what extent the results of this research are relevant and can be applied in future studies and applications. A systematic literature search was performed based on the classification based on the type of 3D printing polymer. The most important process parameters that are believed to influence the tensile and flexural strength of FDM samples are discussed considering the results presented in the literature. A necessary distinction is also made between the mechanical properties of the material, of the specimens and the mechanical behavior of a final FDM part.

Keywords: Rapid prototyping RP, Additive manufacturing, Process parameters, Fused deposition modeling.

1. Introduction

Additive Manufacturing (AM) is considered a method of joining materials to create components after CAD (Computer Aided Design) modeling of a part, layer by layer. The basic principle that drives almost all AM machines is the creation of the virtual solid model, then the data from this model is decomposed into a series of two-dimensional (2D) cross sections, and this fragmented data is transferred to the AM machine, so that they can be combined layer by layer to develop the physical part [1]. AM techniques are broadly classified as (according to

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ISO/ASTM 52900:2015) [2]: tank polymerization (SLA); material jet (Object); binder jet (3DP); material extrusion (ME/FDM); sheet lamination (LOM); powder bed fusion (SLM/SLS); and directed energy deposition (LENS). Fused Deposition Modeling (FDM) was patented by Crump in 1988, who later founded Stratasys Corporation in 1989, which has a simple basic appearance but is capable of fabricating complex geometry. It is an AM fusion extrusion process in which a device driven by an electric motor delivers a filament of raw material. The hot blender melts the filament. The print head/mixer assembly is driven on a platform by stepper motors. The molten filament is pushed through the mixer into the die and nozzle. deposit this melt along the XY plane on the platform (tool less work bench). The lowered platform or print head moves up in the Z direction by exactly one layer thickness after completing the deposition on the next cross section. Therefore, the three-dimensional (3D) structure is created in a layer-by-layer routine. This process continues until the part is built. Early in the FDM process, there is a buildup of material along the edge of the part and then in the inner region of the contour. A specific number of profiles is required to pack the part based on the required response [3].

This literature review can represent a valuable and practical starting point for those who wish to start new research in this field and for the design of new materials, since the connection between materials, process parameters and mechanical properties requires more research to fully understand them. Interactions and their effects. It should also contribute to better planning of experimental studies in this field, to ensure that results are not only of limited value due to specific manufacturing conditions.

2. Mechanical properties of fused deposition modelling parts:

Literature is available on the evaluation of static material properties of the FDM part of various materials. Most research into optimizing FDM process parameters focuses on improving build time, surface finish, dimensional accuracy, and static mechanical properties such as compressive and tensile strength, impact strength, and to bending.

Yang Wu et al. (2005) [4] A range of ground rubber (GR) / acrylonitrile-butadiene-styrene (ABS) compounds have been developed containing various treated and untreated rubber particles. The tensile properties of the different GR / ABS compounds were determined according to the Australian standard 1145-1989, while the surface chemistry of the raw and surface treated GR was characterized by X-ray photoelectron spectroscopy (XPS).

Ludmila et al. (2013) [5] This paper focused on testing the tensile strength of ABS material for the rapid prototyping method of fused deposition modeling. The experimental tests of tensile strength of ABS plastics must be performed in compliance with the international standard EN ISO 527-1 Plastics - Determination of tensile properties.

Angel R. et al. (2014) [6] A comparison was made between pure ABS, two ABS matrix compounds and an ABS / elastomer blend in order to characterize the effect of additives on mechanical properties. Tensile test results of specimens built in different orientations showed that ABS reinforced with 5% by weight of TiO_2 showed the highest maximum tensile strength for specimens built in both horizontal and vertical directions with 32.2 and 18.4 MPa, respectively.

Gorski et al. (2015) [7] The article presents the results of the tensile, bending and impact resistance tests carried out on samples of various orientations, made of ABS material with FDM

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technology. The results of these tests have made it possible to discover a unique phenomenon: with the change of orientation, not only the values of the resistance indices change, but also the macroscopic behavior of the material under load.

Nunez et al. (2015) [8] The aim of this study was to determine the dimensional accuracy, flatness and surface texture achieved in the FDM rapid prototype with ABS-plus as the model material. Two densities (low, solid) and two layer thicknesses (0.178mm, 0.254mm) were used in the experimental test. The best dimensional behavior was obtained with the configuration of maximum layer thickness (0.254 mm) and solid density (100%) with a better surface finish and the minimum flatness error were obtained with lower thicknesses (0.178 mm) and density of solids (100%). This study established optimal configurations for component manufacturing with FDM and ABS-plus 3D printing.

Sa'ude et al. (2015) [9] This article presents the development of a new polymer matrix composite (PMC) material. The material consists of iron powder filled with acrylonitrile butadiene styrene (ABS) and surfactant powder. In this study, the effect of iron powder as a filler material in a polymer matrix composite was investigated and ABS was chosen as the matrix material. Detailed formulations of the composition ratio in percentage by volume (% by volume) with various combinations of the new PMC are studied experimentally. On the basis of the result obtained, it was found that, vol. % increase in iron charge which occurs on hardness, tensile strength and flexural strength.

Garg et al. (2016) [10] This study investigates the simultaneous effect of part construction orientation (along the X, Y, and Z axes) and screen angle (0 °, 30 °, 60 ° and 90 °) on surface roughness, strength tensile strength, flexural strength, wear. Acrylonitrile butadiene styrene (ABS) test samples manufactured using the Fused Deposition Modeling (FDM) process. Mechanical properties and surface roughness show strong anisotropic behavior of the parts. For parts built with the X or Y orientation and a screen angle of 30 ° or 60 °, fiber tensile and a small amount of

taper are observed along with the tear, which is responsible for increased strength.

Christiyan et al. (2016) [11] In this method, 3D digital CAD data is converted directly into a product. In the present investigation, the hydrated magnesium silicate compound ABS + was considered as the starting material. The mechanical properties of the ABS + hydrated magnesium silicate composite were evaluated. ASTM D638 and ASTM D760 standards were followed for tensile and flexural tests respectively. Samples with different layer thickness and printing speed were prepared. Based on the experimental results, it is suggested that the low printing speed and low layer thickness led to the highest tensile and flexural strength, compared to all other process parameter samples.

Weng et al. (2016) [12] Acrylonitrile butadiene styrene (ABS) nanocomposites with modified organic montmorillonite (OMMT) were prepared by melt intercalation. The ABS nanocomposite filaments for fused deposition modeling (FDM) 3D printing were produced by a single screw extruder and printed with a commercial FDM3D printer. The 3D printed samples were evaluated using mechanical thermal, tensile and flexural tests. The structure of the nanocomposites was analyzed by TEM and low angle XRD. The results showed that the addition of 5% by weight of OMMT improved the tensile strength of the 3D printed ABS samples by 43%, while the tensile strength of the injection molded ABS samples improved by 28.9. %. The addition of OMMT has been found to significantly increase the tensile

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modulus, flexural strength and flexural modulus. These new ABS nanocomposites with improved mechanical properties could be promising materials used in FDM 3D printing

Akessa et al. (2017) [13] This article presents a study carried out to characterize the mechanical properties of ABS-M30 materials whose samples are made using different printing parameters. To understand the mechanical properties, it is crucial to study the effects of printing parameters on 3D printed parts. For this, the design of experiments (DOE) is used. The printing parameters of the machine (FDM (Fused Deposition Modeling) Fortus 450mc machine) such as screen orientation, air gap and screen width, were examined to test the tensile strength. The study shows that the raster orientation and the air gap have a greater effect on the mechanical properties of ABS-M30 products where the raster width has less effect.

Panes et al. (2018) [14] The objective of this study is to compare the effect of layer height, fill density and layer orientation on the mechanical performance of the PLA and ABS test samples. The variables that are studied here are the elastic limit for traction, the tensile strength, the nominal strain at break and the modulus of elasticity. The results obtained with ABS show less variability than those obtained with PLA. In general, the percentage of fill is the production parameter that affects the results the most, although the effect is more evident in PLA than in ABS.

Osman et al. (2018) [15] Design / methodology / approach: RS and ABS were developed and blended with a variable fiber content (5-15%). The filament used by each blend was produced using a single screw extruder. The mechanical properties were then tested according to ASTM standards. Scanning electron microscope images were also taken of the samples. The traction properties decreased as the RS content increased. However, the 0 ° screen angle samples showed better tensile properties than the 45 ° screen angle samples, indicating that the tensile properties of the FDM parts are anisotropic. Flexibility properties decreased with increasing fiber content, but increased to 15% fiber content. The water absorption of the composite material is increased with increasing fiber content.

Petruse et al. (2019) [16] This article aims to identify the parameters that have the greatest influence on the parts obtained with the fused deposition modeling (FDM) technology from ABS material. Furthermore, this study identifies the most accurate methods for testing the mechanical properties of FDM parts while still meeting the ASTM standard for testing the tensile properties of plastics. ASTM D638-02a type I samples were found to be the most suitable for testing high anisotropic plastics.

3. Results and discussion

The articles examined were grouped into different categories of polymers used in FDM: ABS (tensile properties) - table. This classification was applied to facilitate FDM users and researchers to find information when they own a 3D printer and material and want to know which studies present details on the relationship between process parameters and mechanical properties or details on the optimal parameter setting from a different mechanical properties perspective.

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Table: 1 Tensile Property of ABS Material Used in FDM.

Researcher	Material	Significant factor	Tensile strength	Tensile Modulus	% of Elongation	% of Strain Failure
Yang Wu et al. (2005)	Ground Rubber (GR)/ABS	-	11.4 ± 0.2	645 ± 11	-	-
Ludmila et al. (2013)	ABS	Gauge length	29 Mpa	-	-	5.06
Angel R. et al. (2014)	ABS PURE Horizontal SPECIMAN	ABS 5% TiO2	32.2 MPA	1708	-	2.0
	VERTICAL SPECIMAN		18.4	1355	-	2.0
Gorski et al. (2015)	ABS(bending)	Raster Angle, Layer thickness	Maximum deflection (dl) mm 6	Bending strength (MPa) 35.1	Maximal strain (%) 3.5	-
Gorski et al. (2015)	ABS	Raster Angle, Layer thickness	19.0	1.6	-	4.6
Nunez et al. (2015)	ABSplus-P430	-	33 MPa	2.200 MPa	2%	6%
Sa'ude et al. (2015)	Iron-ABS	-	9.22 MPa	Break Stress 8.72 MPa	-	-
Weng et al. (2016)	ABS with OMMT	OMMT Powder (1 wt%, 3wt%, 5wt% of ABS pellets,	39.48	-	3.6	-
Garg et al. (2016)	ABS & chemical (dimethyl ketone) treatment	Part Orientations and Raster Angles	Chemical Vapour treatment(X – axis) 33 MPa	dimethyl ketone Vapour treatment (Y-axis) 32 MPa	Chemical Vapour treatment (Z-axis) 32 MPa	-
Akessa et al. (2017)	ABS-M30	raster width, air gap and raster orientation.	31.67	-	-	3.48
Osman et al. (2018)	(ABS)-rice straw (RS)	Raster angle	38MPa	550 MPa	-	-
Panes et al. (2018)9	ABS	layer height, infill percentage, manufacturing orientation	42.35	1.49	-	19.58
Petruse et al. (2019) 10	ABS	-	22.1 - 49.0 MPa	1.50 - 2.60 GPa	3-150%.	-

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4. Conclusions and research perspectives

It is necessary to understand the interdependence of process parameters, material, and mechanical behavior of FDM samples and parts in order to assess whether objects can meet the specific mechanical requirements of the applications for which they are manufactured. This article reviewed the literature focusing on the influence of different process parameters on the mechanical properties (tensile and flexural) of the samples when considering their individual and/or combined effect. For the different polymers, sets of values (levels) were assigned for the process parameters and the mechanical properties of the sample were measured. Test standards will be developed for FDM samples containing information about 3D printing conditions. Standardized parameters can include layer height, fill rate, production orientation Among the mechanical properties, tensile strength is the most valued. Smaller values of layer thickness and texture width are reported to improve tensile strength. Furthermore, the mechanical properties are improved by establishing a negative plot in an air gap. For the application of FDM parts in the medical field, sterilization is performed. Furthermore, research efforts are also needed for the advancement of technology, development of new materials and automation of the FDM process due to its wide acceptability in industries. In research it is also necessary to convert waste into a useful product to increase the economic cost of waste, while reducing the polluting load generated by these industrial production units.

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