Sigma J Eng & Nat Sci 36 (3), 2018, 667-675

Sigma Journal of Engineering and Natural Sciences
Sigma Mühendislik ve Fen Bilimleri Dergisi

Research Article

DEVELOPMENT OF HYBRID PATTERN FOR THREE DIMENSIONAL PRINTING OPTIMIZATION

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Received: 08.05.2018 Revised: 11.07.2018 Accepted: 10.09.2018

ABSTRACT

The aim of this study is the development of a hybrid pattern for 3D printed object via Fused Deposition Modeling Technique (FDM). In the previous study, a tensile test simulation was applied to the specimens with linear, hexagonal and diamond infill patterns. These patterns were designed with 50% infill density. Nodal displacement was applied as 0.04 mm to specimens as 8 steps to create realistic tensile test simulation. For comparison; the key parameters for structural strength and pattern influence were obtained from the simulation results. Tensile test simulation showed that hexagonal pattern has the lowest degree of occurred stress values and provides highest factor of safety for 50% infill density, when compared with the other type of pattern types.

An optimization process was conducted in this study to gain better results for 3D printing by considering the parameters of manufacturing time, material consumption and structural strength. In optimization process, the tensile test simulation results of the specimens with different patterns were taken into consideration. The stress raiser zones (stress concentration) show the maximum occurred stress. They were reinforced with the hexagonal pattern. Clamped section and straight zones were designed with the pattern type of diamond for optimization. The pattern of the hybrid system was created with 64% of diamond and 36% of hexagonal. Structural analyses were applied to designed specimens with hexagonal, diamond and hybrid types of infill patterns.

The results showed that manufacturing time and material consumption increased 2 minutes and 0.2 g respectively. 12 % strength and more ductile structure were obtained with hybrid pattern. Therefore, it can be concluded that the developed hybrid pattern is optimum for 3D Printing Technology.

Keywords: Stress concentration, hybrid pattern structure, pattern optimization, structure reinforcement.

1. INTRODUCTION

Additive manufacturing (AM) is defined as “the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining” [1]. AM can deliver parts of very complex

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geometries with minimum requirement for post-processing, built from materials such as plastic and metal close to zero material waste. AM offers to designers and engineers an increased design freedom ability and enables to create special products. Prototypes and products can be manufactured with l ow cost. An important example of the design freedom in conventional assemblies can be re-designed in a single complex structure through AM that could not be manufactured with the current manufacturing processes. Another indicative feature of AM technology is environmentally and ecologically promising. Additive manufacturing technologies and methods are increasing constantly in terms of application and market share, spreading into various manufacturing divisions, such as automotive, medical and aerospace, and are expected that this heavy growth will continue over the years [2].

In 2015, the AM industry, consisting of all AM products and services worldwide, grew 25.9% to $5.165 billion (CAGR-Compound Annual Growth Rate). This compares to 35.2% growth in 2014, when the industry reached $4.103 billion. The CAGR for the past three years (2013–2015) is 31.5%. The CAGR over the past 27 years is an impressive 26.2%. This $5.165 billion estimate of worldwide revenues includes both industrial systems and desktop 3D printers (those that sell for less than $5,000). In 2015, growth in unit sales of desktop 3D printers continued at a strong rate, increasing by 69.7% to an estimated 278,385 machines. Growth in 2014 was 88.0%, with unit sales of 163,999 machines. Average unit sales growth over the past four years (2012–2015) was 87.3% [3].

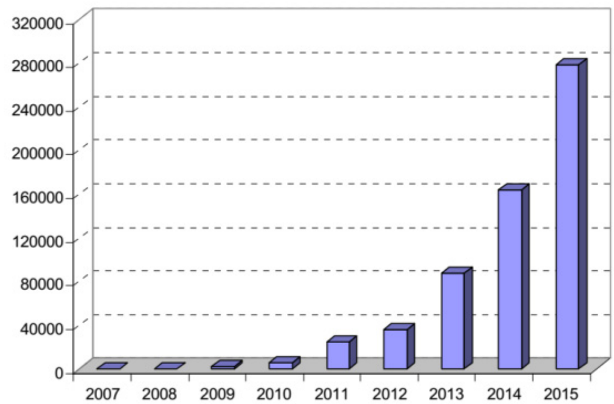

Figure 1. Desktop 3D printer machines annual sale (Wohlers report 2016)

Among the most widely used and rapidly growing additive manufacturing (AM) technologies are extrusion deposition processes such as fused deposition modeling (FDM), fused filament fabrication and melt extrusion manufacturing (MEM) [4].

Today; a large number of additive manufacturing processes are available. They vary in the way as;

- Layers that are deposited to create parts,
- The operating principle,
- The materials that can be used for manufacturing.

Some methods; selective laser melting (SLM), selective laser sintering (SLS) and fused deposition modeling (FDM), melt or soften materials to produce the layers. Others are stereolithography (SLA) cure liquid materials. Each method has its own advantages and drawbacks. The main considerations made for choosing a machine are generally its speed, cost, range of materials as well as its color and manufacturing size capabilities [5]. Most commonly used methods can be categorized as laser and extrusion based processes.

1.1. Laser Based Manufacturing

Laser based additiv e manufacturing processes use a laser source of medium to low power in order to melt, solidify or cure the material (Figure 2). The laser based systems can be divide in two sub categories; depending on the phase change mechanism, laser melting and laser polymerization. In the laser melting processes, the material is supplied, in the form of powder, either to a powder bed or via nozzles directly to the processing head. A laser beam is used in order to melt the material, then cools down and solidifies for production. Laser melting methods can be listed as; Selective laser sintering (SLS), Selective laser melting (SLM), Direct metal laser sintering (DMLS), Laser engineered net shaping (LENS), Direct metal deposition (DMD), Laser powder deposition (LPD), Selective laser cladding (SLC). In laser polymerization, the material is usually a photosensitive resin than can be cured upon its exposure to UV radiation, provided by a low power laser source. They can be categorized as; Stereolithography (SLA), Solid ground curing (SGC), Liquid thermal polymerization (LTP), Beam interference solidification (BIS), Holographic interference solidification (HIS) [2,6].

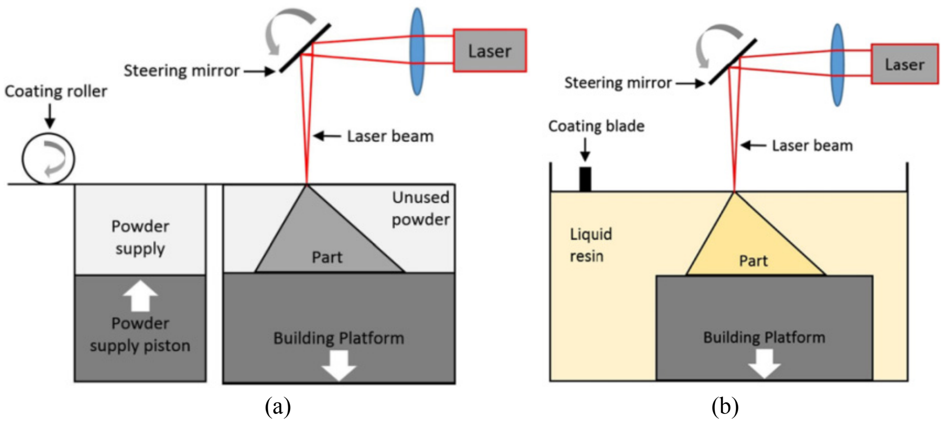

Figure 2. Laser based AM methods a) Laser melting b) Laser polymerization [7]

1.2. Extrusion Based Manufacturing

In a typical extrusion process (Figure 3), a material filament is fed into machine through a pinch roller mechanism. The feedstock is melted in a heated liquefier with the solid portion of the filament acting as a piston to push the melt through a print nozzle. A gantry moves the print nozzle in the horizontal x-y plane as the material is deposited on a build surface that can be moved in the z direction.

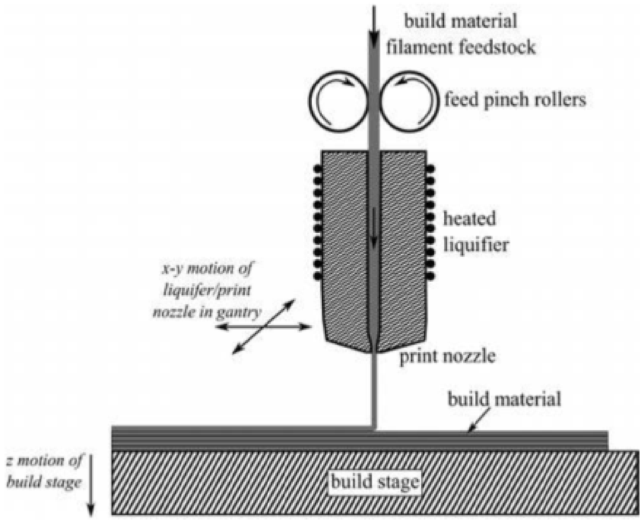

Figure 3. Typical extrusion based process [6]

1.2.1. Fused Deposition Modeling (FDM)

This method uses a movable head, deposits a thread of molten thermoplastic material onto a substrate. The material is heated up to 1 °C above its melting point, so it solidifies right after extrusion and then welds to the previous layers. Recent FDM system heads include two nozzles; one for the part material and one for the support material. It can be viewed as a desktop prototyping facility, since it uses cheap, non-toxic, odorless materials, in a variety of colors and types, such as acrylonitrile butadiene styrene (ABS), medical ABS, PLA, investment casting wax and elastomers. The simplicity of the FDM process, the relatively cheap equipment and the raw materials render its use ideal by hobbyists as well as the production of low-cost plastic parts. However, accuracy and surface quality are relatively poor when compared with other AM processes [8,9].

1.2.2. Robocasting

It is a fabrication technique that is based on layer wise deposition of highly loaded colloidal slurries for dense ceramics and composites. The process is completed generally with less than 1 % organics and the parts can be fabricated, dried and completely sintered in less than 24 hours [10].

In this study; a hybrid pattern was developed for 3D printed object using PLA material via FDM technique with the obtained analysis results of the previous study name of "Comparison of Three Dimensional Printing Infill Patterns Influence to Structural Strength". An optimization process was conducted in this study to gain better results for 3D printing by considering the parameters; time, material consumption and structural strength.

2. MATERIAL AND METHOD

According to obtained results from the previous study with tensile test simulation the hexagonal type of infill provides the strongest structure. In the previous study a tensile test simulation was applied to the specimens with linear, hexagonal and diamond infill patterns. These patterns were designed with 50% infill density. Nodal displacement was applied as 0.04 mm to specimens as 8 steps to create realistic tensile test simulation. For comparison; the key parameters for structural strength and pattern influence were obtained from the simulation results. However, more consideration by means of time and material consumption is required to accept this pattern as the optimum to create the parts. A comprehensive comparison was conducted in this study to create a hybrid type of infill pattern.

2.1. Stress Concentration

During the design phase of an engineering component, it is critical to consider safety parameters that define the efficiency of the mechanism. Basic stress analysis and calculations are performed at the initial phase assuming the components are smooth, having uniform profile and without irregularities. However, in actual all engineering components have at least minimal changes in section or shape like shoulders steps on shafts, holes for oil, key ways and screw threads can impact on distribution of stress. Discontinuities in the components that lead to local increase of stress is referred to as stress concentration. Stress concentration factor (Kt), is a dimensionless factor which is used to quantify how concentrated the stress is in a material. It is thus defined as a ratio of the highest stress in the element to the reference stress. So it is important to analyze the component for stress concentration in order to have proper functioning of the component with safety. Otherwise the fabricated/manufactured component will not be fully functional with load; this might further hamper the balance of the system and cause severe effects. Stress concentration is the functions of;

- Shape of the component,
- Type of loading applied to the part such as axial and bending.
- Specific geometric stress raiser in the part such as fillet radius, notch and hole.

2.2. Structural Analysis

Structural analysis was applied to tensile specimens with raw PLA, linear, hexagonal and diamond patterns using Ansys Workbench Software in Static Structural Analysis environment to check stress concentration zones and comparison (Figure 4).

In structural analysis; 1,100 N force was applied to specimen from two sides as half values of total. The meshes were created with 5,800 nodes and 4,800 elements. To obtain better analysis results; the minimum element size, edge length were defined as 1.26 and 0.06 mm, respectively.

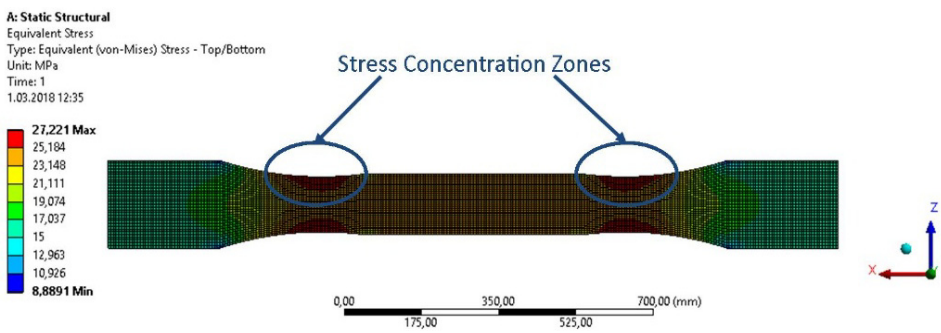

Figure 4. Stress concentration zones

2.3. Parameters for Hybrid Pattern Design

Manufacturing time, material consumption, geometric stress raiser zones and structural strength were taken into consideration to create hybrid pattern. According to the tensile test simulation result; occurred stress values for linear, hexagonal and diamond patterns reached to 59.1, 47.4 and 70.7 respectively at fifth step. Therefore; for the structural strength, the patterns can be classified as Hexagonal > Linear > Diamond.

The related parameters obtained from the MakerBot Z18 Model Desktop MakerWare Software, structural analysis and tensile test simulation Table 1.

Table 1. Comparison parameter values for different infill types

Equivalent maximum stress at fifth step	**(MPa)**
Linear	59.1
Hexagonal	47.4
Diamond	70.7
Strain at fifth step	**(%)**
Linear	5.3
Hexagonal	5.1
Diamond	6.5
Material consumption	**(g)**
Linear	12.3
Hexagonal	14.2
Diamond	11.2
Manufacturing time	**(min)**
Linear	30
Hexagonal	37
Diamond	32

2.4. Design of Hybrid Pattern

According to the comparison parameters, a hybrid pattern was designed using a CAD software package (Autodesk Inventor). A non-uniform stress distribution on tensile test simulation specimen was expected cause of the stress raiser zones. To obtain more homogenous distribution and lower stress level with minimal material consumption increasing and manufacturing time a hybrid pattern was designed (Figure 5).

Figure 5. Design of Hybrid Pattern

The design procedure was completed with the following steps;

1. The stress concentration zones were determined with the structural analysis,
2. The lower stressed places (clamped section and straight zone) were re-created with diamond pattern as it has the lowest level of manufacturing time and material consumption,
3. The stress concentration zones were reinforced with hexagonal pattern,
4. Transition places from preceded to next pattern were supported with bridges to make new type of pattern applicable for 3D Printing.

3. RESULTS AND DISCUSSION

Structural analysis was applied to specimen that was designed with new type of pattern, hybrid, to gain better results. The pattern of the hybrid system was created with 64% of diamond and 36% of hexagonal. Consequently, it was expected that less material is consumed, manufacturing time is also decreasing, stress distribution is more uniform and structural strength is better.Structural analysis of diamond, hexagonal and hybrid patterns for stress distribution is shown in Figure 6.

The structure with hybrid pattern shows more uniform stress distribution as expected. A significant observation from the analysis that the maximum stress zones shifted from radius to transition of patterns. This can be explained with the geometric shape effect. Occurred stress for the radius places were decreased with the reinforcement. Bridges, created for transition, exposed more nodal stress, this may be the result of unfinished diamond and hexagonal patterns at transition zones.

As given in the Table 2, maximum equivalent stress was decreased with the hybrid pattern. For structural strength, the patterns can be classified as Hybrid > Hexagonal > Diamond. Normally, hybrid is expected to mid of the diamond and hexagonal. However, effects of the connection bridges provided better results.

Although, the similar behavior is expected by means of strain the obtained results are contrast with the occurred stress values. More strain values than others were observed for hybrid pattern. It can be concluded that with the hybrid system, stronger and more ductile structure was obtained.

The manufacturing time and material consumption increased 2 minutes and 0.2 g respectively. 12 % strength and more ductile structure were obtained with hybrid pattern. Therefore, it can be determined that the developed hybrid pattern is optimum for 3D Printing Technology.

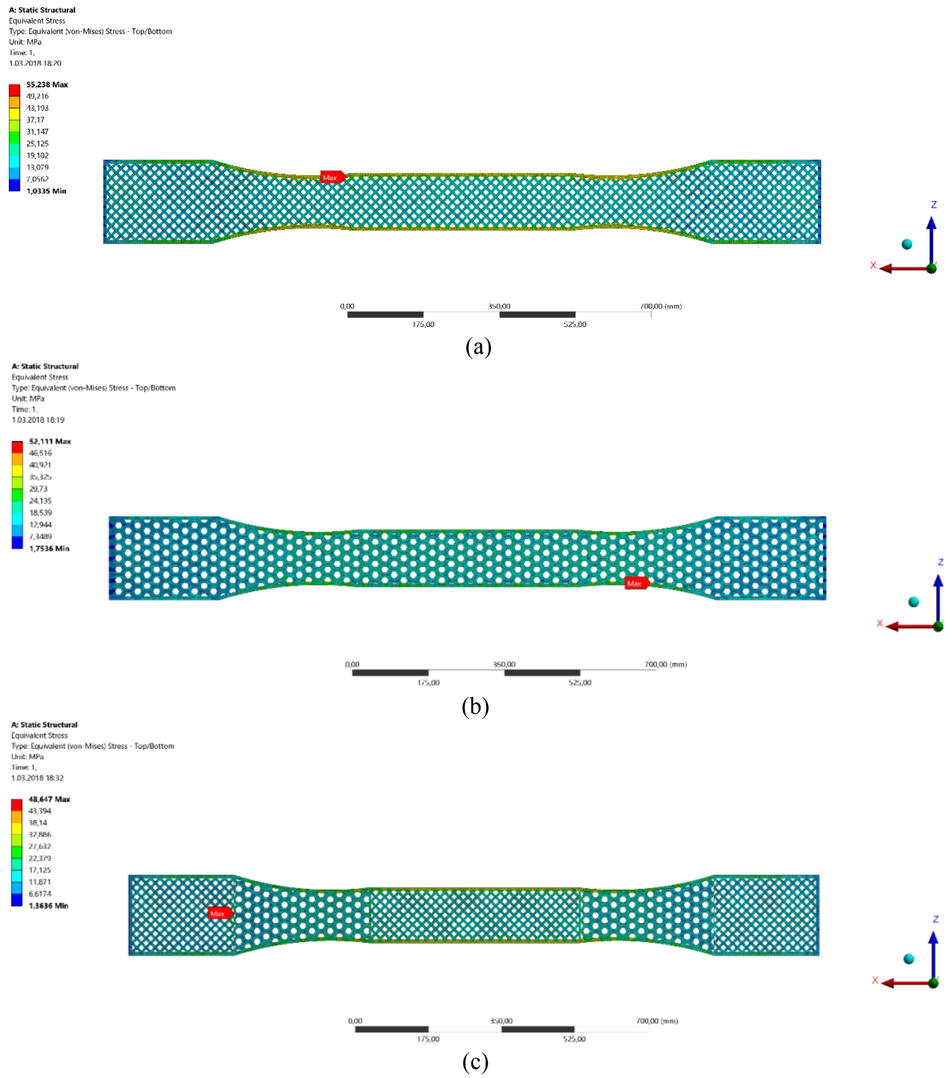

Figure 6. Stress distributions a) Diamond b) Hexagonal c) Hybrid

Table 2. Stress-strain values for patterns

	Diamond	**Hexagonal**	**Hybrid**
Stress (MPa)	55.2	52.1	48.6
Strain (%)	4.5	4.1	6.3

4. CONCLUSIONS AND RECOMMENDATIONS

In this research, a new type of infill pattern for 3D Printing manufacturing system has been developed. The structural strength and other mechanical properties were investigated with analyses for optimization.
Findings from the analyses show that:

1. The structure with hybrid pattern showed more uniform stress distribution as a result of maximum stress zones shifting from radius places to transition bridges and reinforcement.
2. Occurred maximum equivalent stress was decreased with the hybrid pattern. For structural strength, the patterns can be classified as Hybrid > Hexagonal > Diamond.
3. The manufacturing time and material consumption increased 2 minutes and 0.2 g respectively.

12 % strength and more ductile structure were obtained with hybrid pattern.

4. More strain values than others were observed for hybrid pattern. It could be understanding that with the hybrid system, more ductile structure was obtained. However, more research and experimental applications are required to support the idea and further developments.

Further researches are planned to develop a software update to create the parts with 3D Printer using hybrid pattern to produce the tensile test specimens for experimental tests and analysis.

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