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The influence of cellular structures on flow stress of high strength components manufactured using SLM

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Abstract
Additive manufacturing has shown significant improvement in material and machines for high-quality solid freeform fabrication processes such as selective laser melting (SLM). In particular, manufacturing lattice structures using the SLM procedure is of interest. This research examines the effect of cellular materials on compression strength. The specimens are manufactured additively using industrial 3D printing systems from high-strength alloy. The material has the right mechanical properties for manufacturing tool components. This includes samples with solid and lattice structures. The Compression tests are applied to the both samples while they are deformed. The flow stress curves from this research show that using cellular material significantly reduces the yield stress of the samples. This reduction compromises the efficiency of the new structure with respect to the material save.

Additive manufacturing, Selective laser melting, Lattice structures, Compression test, Compression strength, tooling application

1. Introduction

In tooling applications, increasing maximum achievable lifetime of tool components is highly desirable. Tools are commonly manufactured from precious materials with high performance properties for heavy-duty applications and volume production up to millions of parts. When manufacturing tools from blocks, there is a material loss due to the machining processes. This unwanted waste of valued materials is primarily controlled by using the blocks which are roughly close to the shape of tool components. For some applications which require complex tools such as the automotive and aircraft industries, several simpler and smaller inserts must first be constructed and then assembled in the main tool base. In addition, there are locations in the mould where the material carries low stress compared to critical regions and necessarily has no need for using tooling material .Depending on the complexity of the tool, traditional ways of manufacturing tool components, can be costly to the manufacturer. In order to address this problem, a manufacturing process must be developed which allows complex tool components to be made close to the net shape and using tooling material wisely, where it is needed.

Recently, new advancements in material and machine tools for additive manufacturing technologies (AM) enabled small-scale series of production and tooling applications known as rapid production and rapid tooling respectively [1]. In addition, using material in the parts where it is needed is the basic concept for cellular solids and has several benefits for advanced lightweight engineering applications.

Powder metal-based systems such as selective laser melting (SLM) and electron beam melting (EBM) are extremely versatile and allow manufacturing of complex cellular structures while positioning the cells at specific locations throughout of the part in repeated layers [2].

This research focuses on using AM technology for manufacturing tool components (Rapid tooling). The purpose of this research is to examine the effectiveness of cellular structures on the strength of tool components manufactured by selective laser melting procedure in order to achieve lightweight design-efficient structures in tooling applications.

2. Concept of lattice structures

A lattice is a web of struts, and lattice structures are an array of unit cells making up of struts rigidly bonded. Similar to metal foam, an important division of lattice structures is into open-cell structures and closed-cell structures. In closed-cell structures, a solid shell surrounds the web of struts, when open-cell structures has no wall around. Fig. 1 shows an example of open-cell structure additively manufactured by SLM procedure.

Figure 1. An example of open-cell structure.

The purpose of lattice structures is to introduce an alternative to the solid material with the unit cells such that the new structure can be lighter and having the same mechanical properties to a great extent.

3. Compression test

For tool components used in applications such as punching and injection moulding, the predominant force applied to the tools is compressive. In order to determine the flow stress curve, a compression test was used for closed cellular structures fabricated by SLM system. The specimens are cylinders with the length to diameter ratio of 1.6 when using 46 mm height and 28 mm diameter (Figure 2). To provide a means of establishing the cells' effect, solid samples manufactured by the same machine were used for baseline tests. Also, to verify the repeatability of the results, three specimens were tested for each structure.

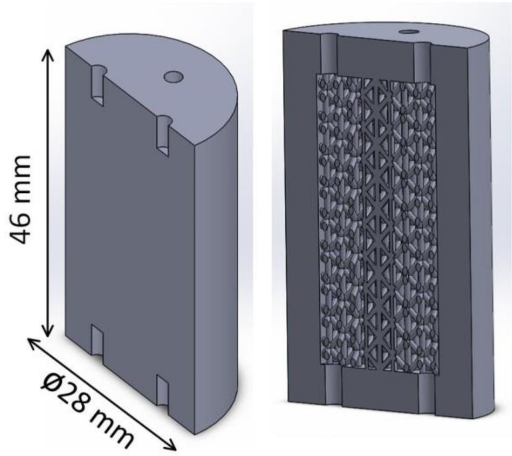

Figure 2. CAD model of solid and closed cellular structure manufactured by SLM.

The material used in the SLM machine is a pre-alloyed ultra-high strength steel in fine powder form. The composition corresponds to 1.2709 (X3NiCoMoTi 18-9-5). For the compression testing described here in, a hydraulic press applies the force to hardened platens, as shown in Figure 3. The specimens need finishing-processing, since they are heat-treated after the SLM procedure to achieve optimal hardness and strength. Therefore, the surface properties are changed by glass blasting in order to mechanically remove material flakes. The force measurements rely on the built-in load cell of the press while three displacement sensors monitor the stroke.

Figure 3. Experimental setup.

4. Results

The compression tests were performed in dry friction condition. The reduction height in the tests is 24% ($\bar{\varepsilon} = \ln(h_0/h)$). When performing the compression test, while reducing the height from 46 to 36 mm, a barrelling effect is observed in the squeezed specimen, as can be seen from Figure 4.

The curve of the engineering stress versus displacement (contraction), associated with the compression test is shown in Figure 5.

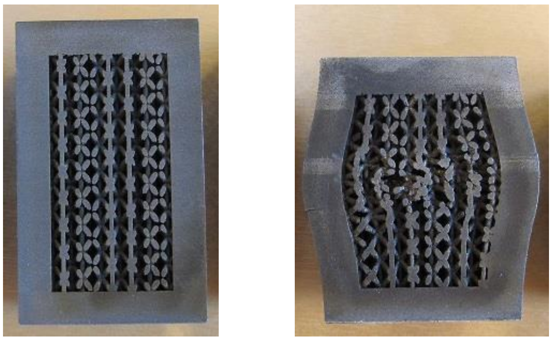

Figure 4. Initial sample (Left) and deformation due to compression test (Right).

The compression strength is used for comparison purposes. When applying the conditions associated with the compression test, considerable decrease in the overall yield stress of the sample with cellular structures is observed in comparison to the baseline behavior. The cellular material's overall flow stress while squeezed is reduced with respect to solid samples; yielding an average compression strength from using cellular structures of only 1050 MPa corresponding to 34% reduction from the baseline (1600 MPa).

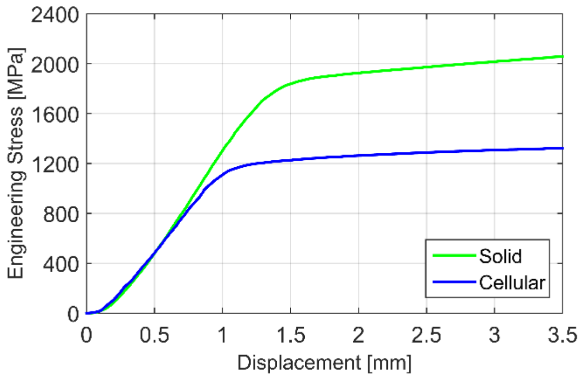

Figure 5. Flow stress profile.

To provide a more detailed analysis of the lattice structure's effect on the material's compression strength, the weight of the specimens is also examined. The solid and cellular samples weigh 220 gr and 170 gr respectively. Back to the main purpose of using lattice structures, the result is somewhat not promising since the strength reduction is far beyond the amount of material saved. Table 1 lists this information and presents the mass reductions as well.

Table 1. Effect of using cellular material.

	Solid	Cellular	Reduction (%)
Comp. strength (MPa)	1600	1050	34
Weight (gr)	224	170	24

5. Conclusion

The effect of cellular material on the yield stress is shown. The analysis includes compression test of cylinders with cellular structures additively manufactured using SLM procedure. Significant reduction of compression strength is obtained for cellular material.

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