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Overview of 3D printing strategies and impact on print quality

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ABSTRACT:

Different technologies of additive manufacturing have their own specifics on which the final quality of the manufactured products depends. In all technologies, production proceeds by adding material layer by layer. But within each layer, it is very important how the material is applied and added. Especially with technologies where high temperature loads are introduced during production, deformations of the final product or individual layers may occur. Such technologies also include selective laser sintering (SLS - Selective Laser Sintering). The aim of the article is to present different methods of strategies in the production of parts by selective laser sintering technology and the impact on the quality of the final product.

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I. INTRODUCTION

If we want to print a dimensionally accurate part on a 3D printer, it is necessary to reduce deformations caused by high residual stress. This residual stress arises during the melting and solidification processes of the material. The formation of these stresses greatly affects the rate of expansion and contraction of the material, or the rapid heating of the material by the laser above its melting temperature, after which a relatively high cooling occurs. Geometric deviations often occur during production due to this stress. This is a significant disadvantage, but despite this, these parts compete with conventional production processes in terms of price, mechanical properties or even surface treatment. In their study, Mercelis and Kruth found that the exposure strategy used to melt the powder layers has a significant effect on the level of residual stress within the part. It was found that changing the scanning strategy leads to different defects, geometric deviations and anisotropy of mechanical properties. [1] [2] [3]

II. EXPERIMENTAL SETUP

In parts printed by selective laser melting, residual thermal stresses can cause the following phenomena:
• voltages are caused by temperature fluctuations,
• stresses are induced in the solid layer, which is located below the currently melting layer,
• stresses are caused by the phase of rapid cooling of the molten upper layers. [4]

With SLM technologies, it is possible to define three main methods of heat transfer: conduction, flow, and radiation (using a laser). The greatest heat transfer in thisin this case, it is a flow between the upper layer and the surrounding atmosphere. In the first case, a phenomenon occurs where in the upper part of the exposed layer there is faster cooling through convection compared to the lower part of the layer, where it is through conduction. The result of this phenomenon is that the upper part shrinks faster than the lower part. [4]

The second phenomenon is referred to as the temperature gradient mechanism, i.e. it is the result of all the large thermal gradients in the solid layer located under the laser, as shown in Figure 1. The lower solidified layers limit the expansion of the upper layer, which is caused by the high temperature gradient. This causes a compressive stress in the upper part of the solid layer, which can reach the value of the material's yield strength and thus cause plastic deformation of this layer. During the subsequent cooling of the upper layers, their compressed state changes to residual stress, resulting in deformation of the part. [4]

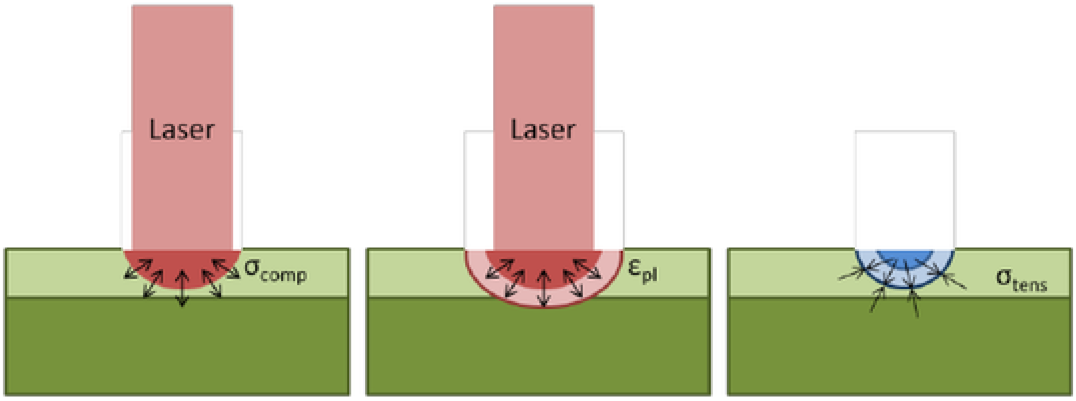

Fig - 1: Side view of SLM technology with temperature gradient mechanism

In the third phenomenon, the upper part of the molten layer shrinks due to thermal contraction of the material. This shrinkage is slower down by lower layers, which results in tensile stress in the top layer and compressive stress in the layer below [4]

III. OVERVIEW OF EXPOSURE STRATEGIES

The exposure strategy includes the length of the scan vector as well as the method of irradiation between successive layers. In theory, this could be any exposure pattern or method used to influence the dependent variable during the SLM process. The process and laser parameters should be different from the exposure strategy because different machines and materials depend on different parameters. Therefore, it would be more beneficial if the exposure strategy was defined on a certain machine for a specific material. [5]

Vector strategy

There are many different layered and vector exposure strategies, each with certain advantages and disadvantages. These strategies affect the material properties of the final part. [6]

- *Alternating vector exposure strategy*

The alternating exposure strategy alternates the vector direction after each exposure. The path of the laser goes along the given vector from its starting point to the end point and then starts a new path on the next vector. The starting point of the next vector must be in close proximity to the ending point of the previous vector. The alternating scan strategy is shown in Figure 2, it can be seen that the directions of the vectors have different directions. [7] [8]

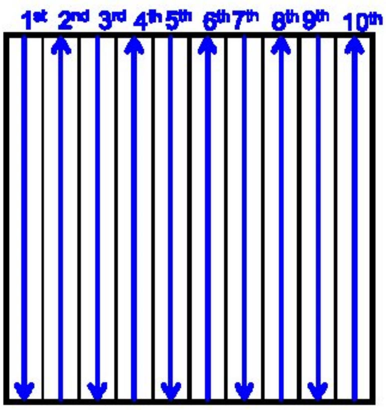

Fig - 2: Alternating vector exposure strategy

- Progressive exposure strategy

The progressive exposure strategy is similar to the alternating exposure strategy except that the exposure vectors are continuous and the laser scanner moves from one vector to the next without any delay or jump. [7] [8] This strategy is shown in Figure 3.

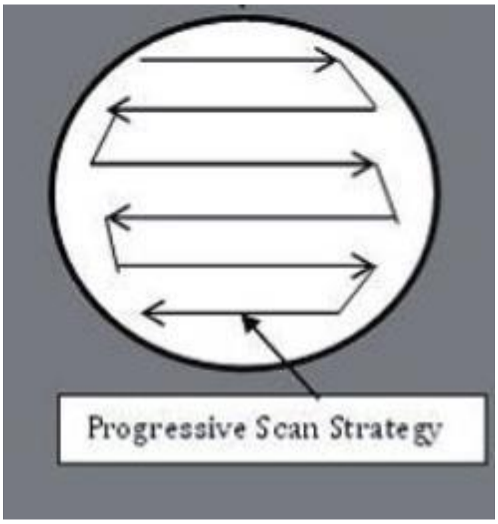

Fig - 3: Progressive exposure strategy

- Spiral vector exposure strategy

The helix scan strategy was developed to reduce deformation in the molten layer caused by steep temperature gradients. This strategy is most advantageously applied to parts with complex shapes. It is necessary to use the Voronoi diagram for each layer. A toolpath algorithm is then used to generate recursive spiral exposure paths for each layer. This means that each exposure path of the individual layers is different, and thanks to this, the strength of the connection is increased. Figure 4 shows this strategy. The vectors could change direction after each exposure, or the vectors could be exposed from outside to inside, or vice versa. This strategy is used to reduce residual stresses and deformations in the part. [9] [10]

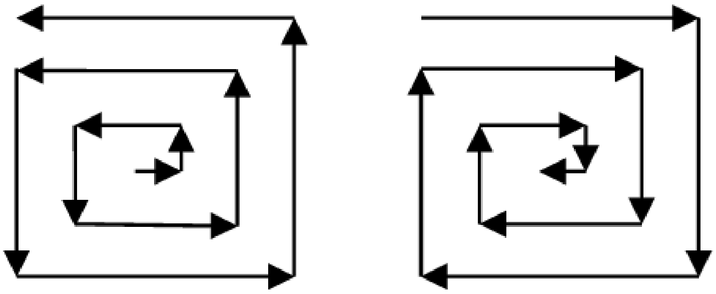

Fig - 4: Vector exposure strategy of the helix

- “Island” exposure strategy

Figure 5 shows the island exposure strategy developed and subsequently patented by Concept Laser GmbH. This strategy tries to reduce thermally induced residual stresses by discretizing the exposed area into smaller parts with a typical size of 5mm x 5mm, also called "islands". These smaller sections are scanned in random order and with shortened exposure tracks. Using this strategy, there is no localized heating of large sections. Localized temperature gradients and consequently residual stresses are thus reduced. [11] [12]

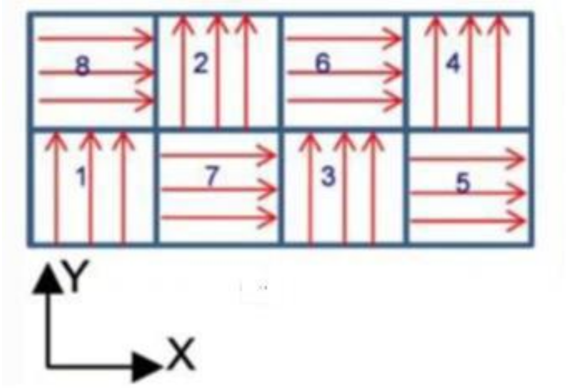

Fig - 5: "Islands" exposure strategy

- Vector hatch fill exposure strategy

This newly developed strategy, which we call the variable helix island scanning strategy, is shown in Figure 6. It was determined by an experiment to observe the effect of the strategy on the deformation of the part. In this experiment, the scanning area was divided into smaller areas called islands, which were individually scanned in the form of spiral vectors. A layer of material in the form of powder was then applied to the work mat, after which the exposure process could begin, which was observed. The exposure procedure in this strategy is as follows: The laser first acts on the island marked with the number 1 and scans the specified vector spiral pattern no. 1 (marked in the smallest spiral). When this pattern is complete, the laser moves to the island marked #2 and scans the spiral pattern #2 there again. 1. Proceed in this way until spiral pattern no. 1 done on all islands. Subsequently, pattern no. is scanned on all islands using the same procedure. 2 etc. The resulting phenomenon is finished patterns on all islands. This procedure should guarantee a reduction of the thermal gradient and yield strength of the material, as a result of a larger time shift between adjacent vectors. The heat that has not had time to dissipate from the scanned vector will act as a pre-heating mechanism for the vector whose position is right next to it and will be scanned next. [13] [14]

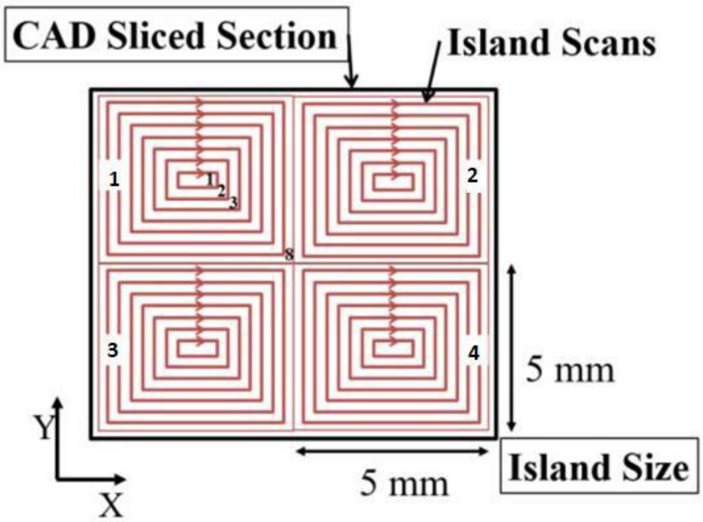

Fig - 6: Vector hatch fill exposure strategy

Stratified exposure strategies

- Strategy of alternating exposure between layers

The strategy of alternating between layers, which we also refer to as the fiber deposition strategy, is used to repair defects in previously scanned layers by scanning the next layer with a certain shift value, so that the laser path is placed in the area of overlap of the scan paths. The reason is that the material in the form of powder, which is in the overlapping area, is very often not completely melted. This strategy is designed to correct this deficiency and thus to melt all the material present in a given overlap region, causing stronger bonds to form between the layers. This strategy is also used to improve surface quality or porosity. It is shown in Figure 7. [15] [16]

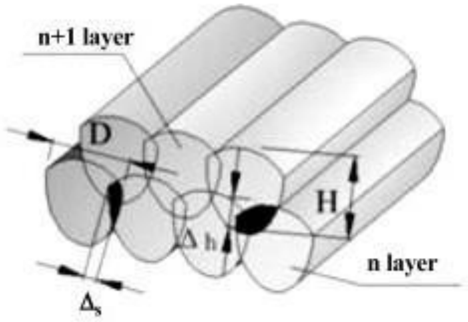

Fig -7: Alternating exposure strategy

- Orthogonal exposure strategy

The principle of this orthogonal exposure is that successive layers are scanned orthogonally to each other. The importance of using this strategy is that it reduces the accumulated stresses along the areas that have already been scanned by the laser, by always changing the scan direction of the next layer. In Figure 8 we can see four layers displayed, of which the first and third were scanned in the y-axis direction, the second and fourth layers in the x-axis direction. Using this strategy reduces the residual stress and porosity of the parts. [15] [16]

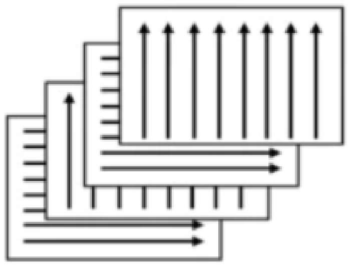

Fig - 8: Orthogonal exposure strategy

IV. CONCLUSION

This article describes some selected 3D printing strategies for Selective Laser Sintering technology. The effect on the tension in the body of the product is indicated, with a description of how they arise and how they can be removed. The stated findings are essential for understanding the events that occur in the material in the process of production and application and processing of the material. Based on this knowledge, it is possible to take appropriate measures to eliminate these adverse conditions.

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