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INVESTIGATION OF LASER METAL DEPOSITION METHOD BY FINITE ELEMENT ANALYSIS: LASER SPEED EFFECT ON THIN WALLED GEOMETRY BUILDING

LAZERLİ METAL YIĞMA YÖNTEMİNİN SONLU ELEMANLAR ANALİZİYLE İNCELENMESİ: İNCE DUVAR GEOMETRİSİ ÜRETİMİNDE İLERLEME HIZI ETKİSİ

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ÖZET

Lazerli metal yığma yöntemi eklemeli imalat yöntemlerinden biri olarak ortaya çıkmıştır. Özellikle sanayide son ürün çıktısındaki malzeme ürün hassasiyeti ve maliyet açısından yaşanan problemler bu yöntemin geliştirilmesinde ve üzerinde önemle durulmasında önemli bir rol üstlenmiştir. Ancak Lazerli metal yığma yönteminde yöntem gereği uygulanan parametrelerden kaynaklı dezavantajları bulunmaktadır. Bu dezavantajlardan birisi ise artık gerilmedir. Artık gerilme imalat sırasında ısınma ve soğuma hızlarına bağlı olarak, malzeme içerisinde kalan basma-çekme kuvvetlerinin etkisidir. Bu çalışmada Lazerli metal yığma yönteminde kullanılan proses parametrelerinin artık gerilme probleminin giderilmesi ve elde edilecek ürünün kalitesinin artırılması üzerindeki etkileri sonlu elemanlar yöntemiyle analiz edilmiş ve termal sonuçları karşılaştırılmıştır. Çalışma için Simufact programından yararlanılmıştır. 3 boyutlu tasarım modül içerisine aktarıldıktan sonra standart parametreler dışındaki değerler üzerinde değişiklikler yapılarak analizler yapılmakta ve bu analiz değerleri karşılaştırılarak artık gerilme üzerindeki etkileri belirlenmektedir. Bu yöntemde analiz için Simufact programı lazer hızı, katman kalınlığı ve sıcaklık parametrelerinde analizler yapılmasına izin vermektedir. Bu çalışmadaki analizler için yöntem parametrelerinden lazer hızı seçilmiş ve analiz sonucundaki karşılaştırmalar lazer hızının etkisini araştırma adına yapılmıştır. Analiz sonucuna göre, lazer hızının artması ile malzemeye uygulanmış olan enerji miktarı azalmasından dolayı maksimum sıcaklık, deformasyon miktarı ve buna bağlı olarak da gerilmenin azaldığı, ancak katılaşmayan bölge miktarının arttığı gözlenmiştir.

Anahtar Kelimeler: eklemeli imalat, lazerli metal yığma yöntemi, sonlu elemanlar metodu

ABSTRACT

Laser metal deposition method has emerged as one of the additive manufacturing methods. Particularly in industry, the product sensitivity and cost problems in the final product output have played an important role in the development and emphasis of this method. However, there are disadvantages arising from the parameters applied in the method of laser metal deposition. One of these disadvantages is the residual stress. The residual stress is the effect of the tension-compression forces within the material due to heating and cooling speeds during the production. In this study, effects of the process parameters used in laser metal deposition method on the elimination of the residual stress problem and the quality of the product to be obtained have been analyzed by the finite element method and the thermal results have been compared. Simufact program has been used for this study. After being transferred into a 3D design module, changes are made on the values other than the standard parameters d the analyzes are made and the effects on the residual stress are determined. In this method, Simufact program allows analysis of laser speed, layer thickness and temperature parameters. For the analysis of this study, the laser speed has been chosen from the method parameters and the results of the analysis have been performed to investigate the effect of the laser speed. According to the results of the analysis, it has been observed that the maximum temperature, the amount of deformation and consequently the stress were decreased due to reducing the amount of energy applied to the material with increasing laser speed, but the amount of non-solidified region was increased.

Keywords: additive manufacturing, laser metal deposition method, finite element method

INTRODUCTION

In Laser Metal Deposition(LMD), powder material is fed to the melting zone simultaneously with the movement of the laser. Powder feeding and laser focusing are carried out by means of the nozzle, concentrically, Figure 1. Since the powder material is not spread over the entire platform, the laser metal deposition technique is particularly advantageous in producing thin wall geometries. With this method, which is actively used in the popular industry such as aerospace and biomedical, the opportunity is provided to obtain physical parts in a short period of time according to the program and part sizes used. Today, companies which use and direct these technologies, develop and make rapid progress in quality, originality and innovation (Ermurat,M 2009).

The most important research topics in methods with high heat input, such as laser metal deposition, have been carried out on the consequences of high heat input on the part. One of the important disadvantages of this method is that residual stresses caused by high heating and cooling which causes faults in the products both during or after manufacturing. In this method, considering the effect area of the laser, a bell-shaped melt pool is formed by the effect of the focused laser beam as seen in Figure 2.

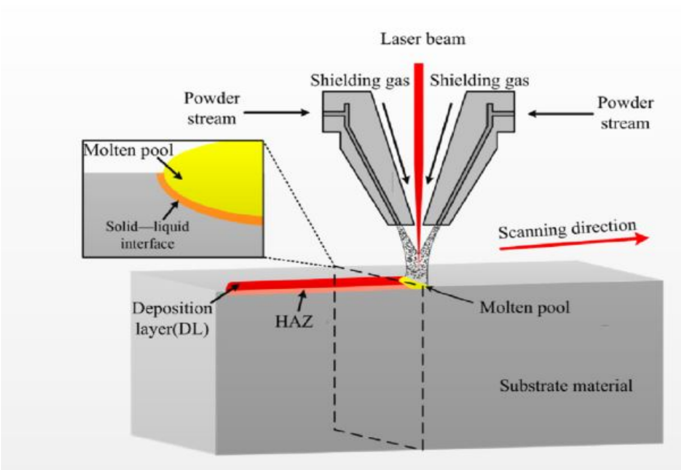


Figure 1. Laser Metal Deposition Process (Zhan, X., et al 2018)

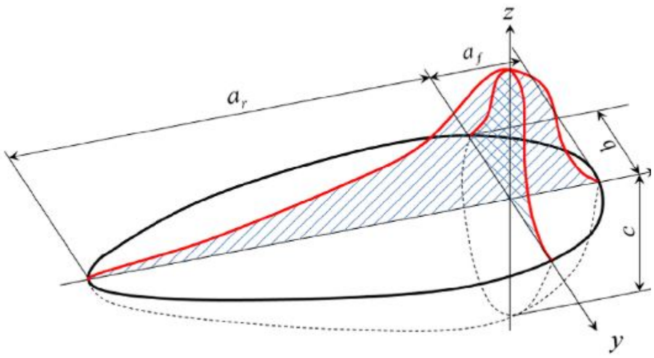


Figure 2. Gaussian Model (Poyraz, Ö. 2018)

This type of melt pool is explained by the Gaussian Dispersion model (Poyraz, Ö. 2018), (Hitz, B. Et al 2001). The laser beam equation that provides the Gaussian density is described below (Koechner, W. 2006).

$$I(\mathrm{r})=I_0 e^{\left(\frac{-2r^2}{w_0^2}\right)} \tag{1}$$

In equation (1), r is the laser beam radius, $I_{(r)}$ is the intensity of laser beam at the radius of r, I_0 is the intensity of laser beam at midpoint of beam and w_0 is the laser spot radius at the interaction level with material. According to the result of the equation, the maximum energy intensity occurs in the middle axis, that is, $r = 0$ point. (Fathi, A. Et al 2006).

The laser beam reaches the melting area following the conical path after exiting the nozzle. On this route, the energy intensity decreases from the mid-axis to the outer diameter. Therefore, the accumulation capacity increases depending on the laser intensity in the middle axis. The intensity of the laser beam, described by the Gaussian profile, is related to the laser power, radius and standoff distance values. (Poyraz, Ö. 2018).

One of the factors that provide the gaussian distribution is the absorption effect of the material. Some of the laser beam that affects the material is absorbed by the material and some of it is reflected. The absorption coefficient, which varies according to the material, is expressed as the ratio of the energy absorbed by the material to the total energy of the laser as seen in equation (2) (Koechner, W. 2006).

$$A=P_A/P \tag{2}$$

In equation (2), A is the absorption coefficient, P_A is the amount of energy absorbed by the material and P is the total energy of the laser.

If the laser is applied to the material for longer than necessity, it causes an increase in the heat affected zone. Thus, this will have negative effects on the mechanical properties of the part. Repeated melting and solidification cycles can cause defects such as porosity, as well as the use of lasers more than necessity to melt the powder material. In addition, these thermal cycles sometimes cause high residual stresses and shrinkage in the final product (Hitsz, B. Et al 2001). Additionally, excess laser power causes an increase in the surface tension (Agarwala, M. Et al 1995). On the other hand, the increase of the heat-affected zone is directly proportional to the excess effect of the laser, which adversely affects the mechanical properties of the material. (Kathuria, Y.P. 1997).

These conditions depend on some parameters. These parameters may include the laser power, layer thickness, scanning speed, scanning pattern, platform temperature, material type, powder size etc. According to the equation given below (Eq.3), four of these parameters change the volumetric energy density.

$$Evol = P/(Vs \cdot t \cdot d) \tag{3}$$

In equation (3), Evol is the volumetric energy density, P is the laser power, Vs is the scanning speed, t is the layer thickness, and d is the clad width, Inappropriate energy densities applied during this process cause local stresses, gaps and some other defects. (Ermurat, M. 2009).

Higher energy density causes extraordinary thermal effects on the parts which is produced with the laser metal deposition methods and residual stresses, shrinkage and microstructural problems based on this thermal effects. By using thermal and thermo-mechanical analyzes with some software using the Finite Element Method, such problems can be analyzed during part design and design optimization.

Analyzes in this project are carried out in two stages. In the various stages of the process, thermal analysis is performed in which the thermal properties of the part are examined as a result of repetitive heat input in the process zone and the heat affected zone.

In addition, mechanical effects such as stress, deformation, tensile and distortion on the substrate and on the geometry to be produced can be examined by thermo-mechanical analysis.

In this study, thermal and thermo-mechanical effects of laser speed on thin wall geometry by Laser Metal Deposition process have been performed with Simufact Welding software using the Finite Element Method.

MATERIAL-METHOD

Simufact Welding software allows variable parameters to be determined such as the laser speed, type of material, laser area and the volume, ambient temperature, laser power, cooling time and acceleration variables for laser speed. Among the variables mentioned, the laser speed has been studied to investigate its effect on the residual stresses.

A simple geometry without complex structure for the analysis has been designed in 3D. The designed geometry has been subjected to certain pretreatment processes in order to make analysis in Simufact program. The designed geometry is defined layer by layer and mesh assignment is made by applying the necessary mesh structure.

The process inputs of the program have been applied respectively for the geometry transferred into the program. Afterwards, analyzes have been performed by changing the laser speed with all other conditions remaining constant. The results have been obtained in the form of graphs and screenshots and comparisons have been made between them.

The model image on the Simufact software screen is shown in Figure 3.

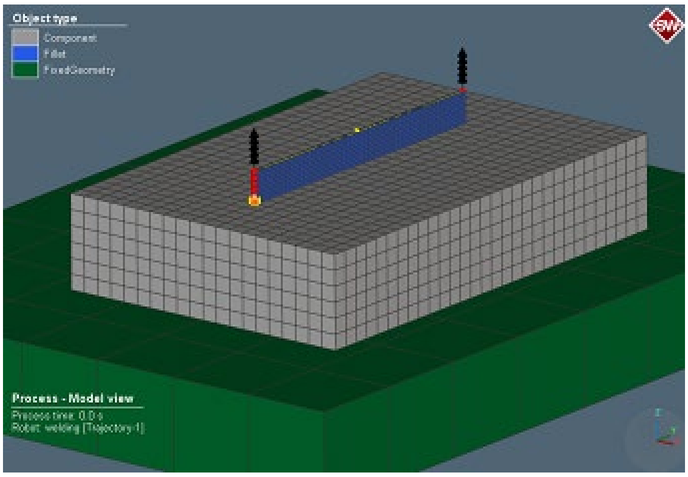


Figure 3. Geometry

The geometry shown in the figure as green is a fixture on which the base (substrate) would be placed. The size of the fixture is 3mm X 15mm X 20mm and it has 3mm element size.

The base, the first layer would be deposited on it, is positioned on the fixture. The size of the base is 2mm X 5mm X 10mm size and it has 0.5mm element size.

The total size of the deposited geometry is 0.2mm X 1mm X 8mm. The geometry consists of 5 layers which are positioned on top of each other. The size of each layer (single clad) is 0.2mm X 0.2mm X 8mm. The element size of the metal deposition geometries has been chosen as 0.1mm.

Some Important Preliminary Parameters Used in this Study

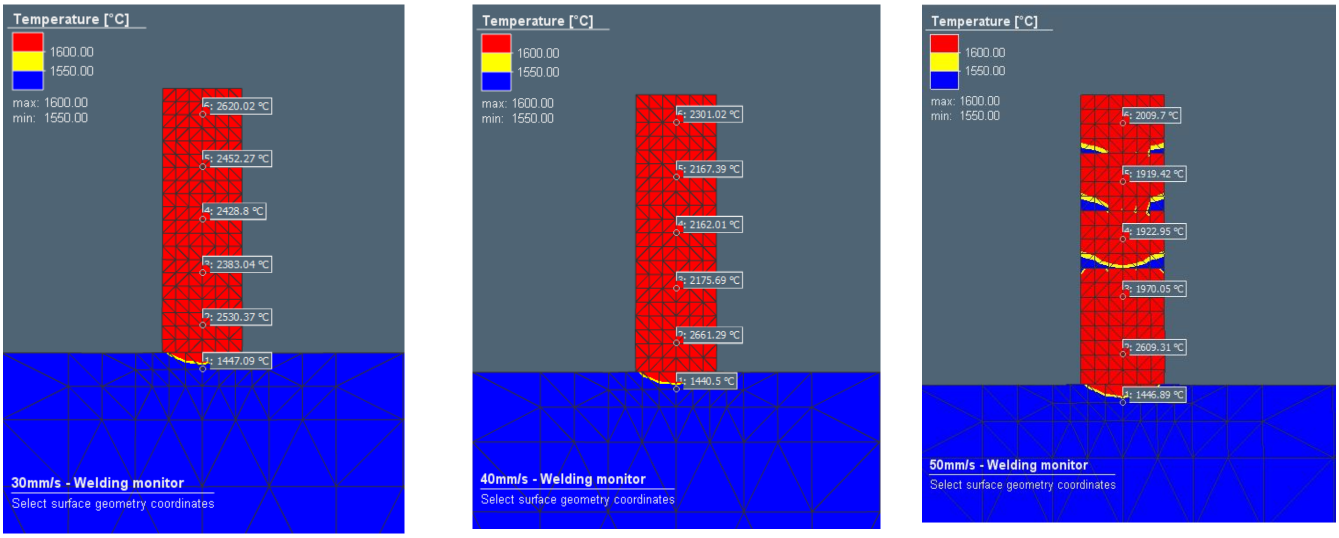
- Mesh Structure; Hexahedral mesh structure, Apex Program, Simufact Refinement was used.
- Material; Ti6Al4V (Solidus Temp: 1400C˚, Melting Temp:1600 C˚)
- Laser Power; 110W
- Laser Flow Characteristics; Max Radius: 0.15mm, Min Radius: 0.14mm, Conical Depth :0.2mm
- Ambient Temperature; 20 C˚
- Efficiency; 0,37 (Material-Laser Absorbsion Ratio)
- Time Between Layers: 3sn

In this study, it is aimed that the affect of the laser speed on the thermo-mechanical properties of thin walled geometry. Thus, three different levels of laser speed have been chosen which were 30mm/sn - 40mm/sn - 50mm/sn.

ANALYSIS RESULTS

For the analysis, melting and peak temperature distributions in the cross-sectional area have been examined from the Welding Monitor section of the program.

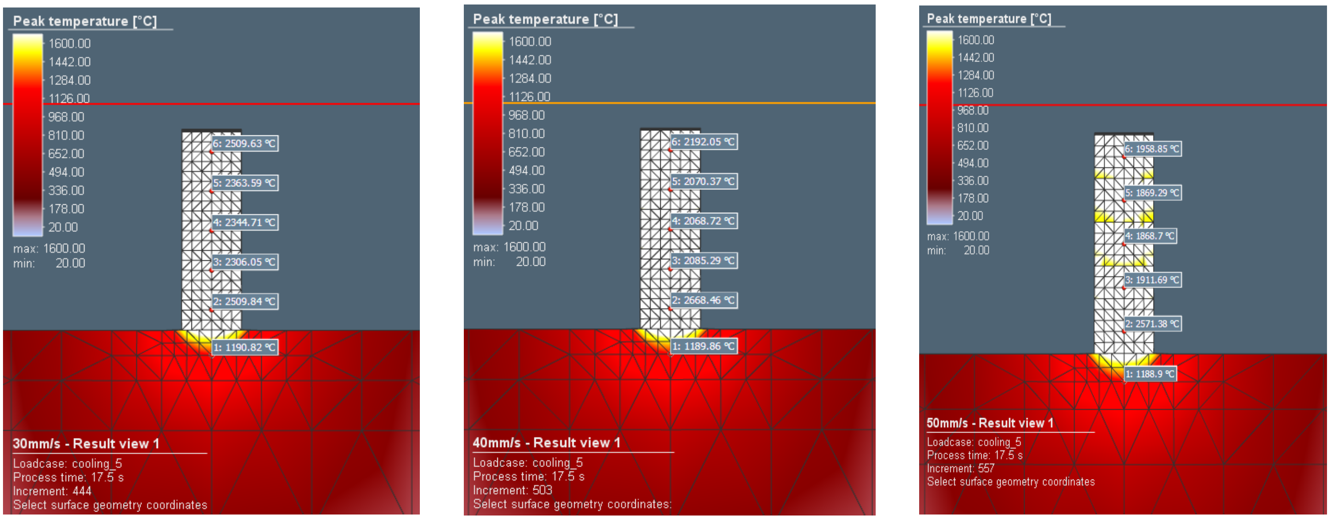
It was observed that as the laser speed increases, the maximum temperature that occurs in each layer decreases. It has also been observed that as the laser speed increases, regions that is away from the center of the laser do not reach the melting temperature haven't been occurred. Figure 4.



30 mm/sn 40 mm/sn 50 mm/sn

Figure 4. Welding Monitor View (Melting-Solidification Observation)

The maximum temperature level in this analysis provides information on whether or not melting can occur and at what levels the values are exceeded. As a result of the analysis, it has been found that the parameters easily provide the melting temperature of Ti6Al4V material, Figure 5.

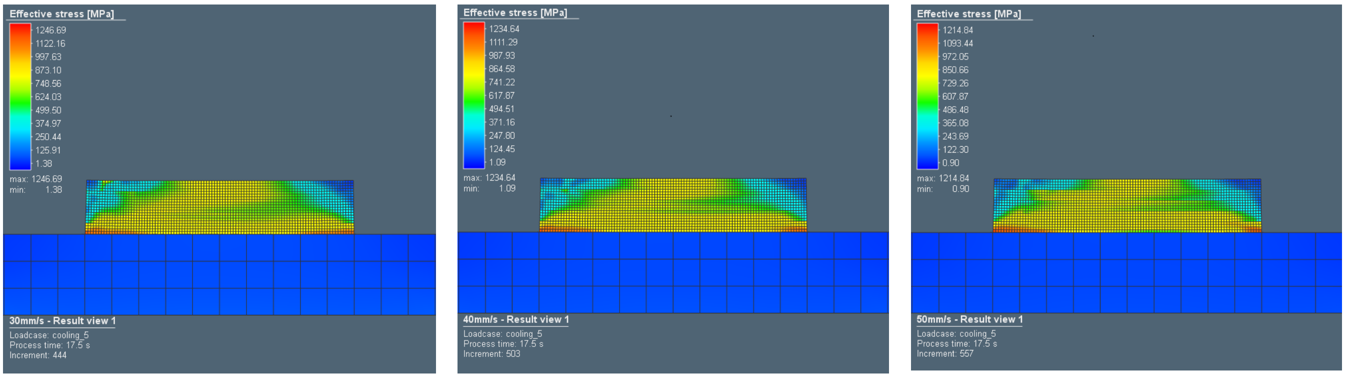


30 mm/sn 40 mm/sn 50 mm/sn

Figure 5. Maximum Temperature Levels

In this process, where repeated high-temperature processes take place, each layer is a cause of the thermal stress. The part subjected to high residual stresses during the heat treatment is deformed after cooling.

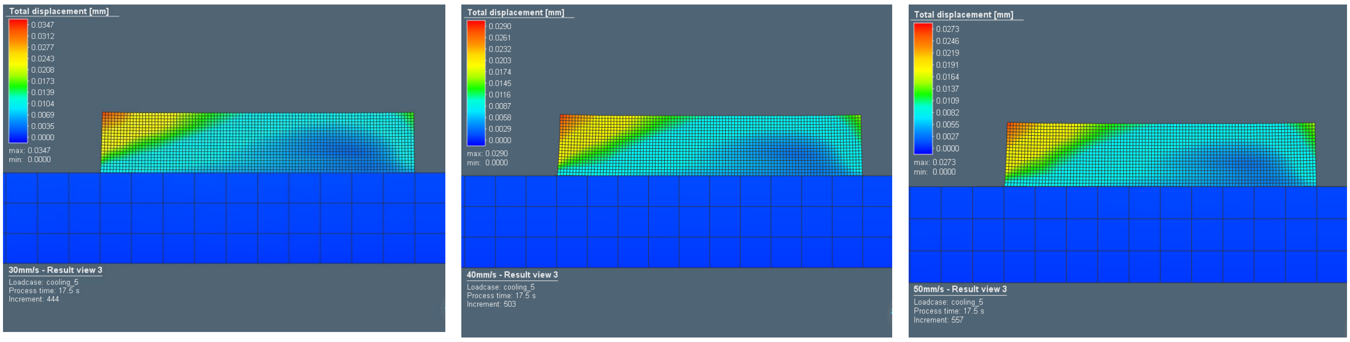
As a result of this analysis, it has been observed that effective stresses decrease as the laser speed increases. This phenomenon can be seen in Figure 6.



30 mm/sn 40mm/sn 50 mm/sn

Figure 6. Effective Stress (VonMises)

Deformation is one of the inevitable facts in this process involving instantaneous heating and cooling processes. Simufact Welding software is able to calculate the amount of deformation occurred. In this analysis, in the formation of thin wall geometry with the laser source having 110W energy, the maximum deformation in the direction of laser progression occurred approximately 0.03mm and this causes shrinkage of the geometry. It is seen that the deformation amount decreases as a result of the effective stress which decreases with increasing laser speed, Figure 7.



30 mm/sn 40 mm/sn 50 mm/sn

Figure 7. Total Deformation

CONCLUSION

As a result of the analyzes, following conclusions can be made;

- Maximum temperature decreases with increasing the laser speed
- Deformation amount decreases with increasing the laser speed
- Stress decreases with increasing the laser speed
- Non-solidified area in the cross-sectional region increases with increasing the laser speed

According to these results, by using FEM Softwares, a combination of laser power and laser speed can be obtained for optimum part building without any solidified region and the lowest energy input to the part.

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