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SIMULATION STUDY ON IMPACT OF ORIENTATION IN METAL ADDITIVE MANUFACTURING ON RESIDUAL STRESSES

[1]Balivada. Sai Bhushan Patnaik, [2]C. L. V. R. S. V. Prasad, [3]P. N. L. Pavani

[1]M. Tech Scholar, [2]Professor, [3]Associate Professor
[1]Department of Mechanical Engineering,
[1]G.M.R Institute of Technology, Rajam, India-532127

Abstract: Additive manufacturing is a layer-over-layer manufacturing technology to build a part. In this rapid prototyping, metal fabrication performs an essential role in the latest advances. In metal parts, residual stress is a limitation that leads to dimensional accuracy and standard of the part. the researchers are concentrated on the stress formation with the support of the simulation tools to study the effect on part quality. In this research, thermal modelling is developed for a 3D component with dimensions of (30mm x 30mm x 30mm) in the ANSYS software in three orientations to know the variations of stresses, temperature distribution, and deformation. In the existing investigation, geometry and orientation are the important variables that impact the stress variation, temperature dispersion, and deformation. The geometry that illustrates is an unsymmetrical section with differential in dimensions from bottom to top that will influence the part with the thermal stress induced in the surface during fabrication which effects the part quality and orientation is a build-up of the volume rate of material for every thickness in each orientation the deposited volume changes that induces the stress generation in the component. Because of thermal stress in the component, which lead to distortion in the component.

***Index Terms* - Additive manufacturing, ANSYS software, orientation, residual stresses, temperature distribution.**

I. INTRODUCTION

Additive manufacturing (AM) is the technique of combining materials to produce products from 3D model data, usually layer wise deposition, as compared as traditional machining [1]. The fundamental distinction between Prototypes and 3d Printing is that AM concentrates on the making of end-user products rather than only models [2]. Additive manufacturing motive is to create the component with potential and net shaped structure with ease and environmental free and sustainable [3]. In the rapid prototyping technology Components are construct layer by layer with a laser of moving heat source used to bond the layers collectively. As a portion of the non-homogeneous heating and cooling processes that induces the thermal stresses which lead to warp in the portion [4]. Aside from the unpredictability of mechanical attributes, other significant challenges include low growth and defective surface integrity, both are crucial to accomplish owing to the topic's restricted modelling ways [5]. Thermal stress and deformation caused by irregular heating and cooling [6] which headed to dimensional inaccuracy of part. so to deteriorate the stresses, thermal analysis is a key factor to describe the stress concentrations in build part. Panagiotis Michaleris had developed a thermal modelling of rectangle thin plate attached to the substrate simulated with the assist of FEA with element kill method including the characteristic of material [7]. D. Riedlbauer et.al developed a temperature distribution will vary because of using process parameters which will affect the part standard [8]. L.dong et.al developed a three-dimensional model of plane plate with geometry of (5mm×0.8mm×0.1mm) had studied on parameters influence the heat dissipation [9]. A fully 3D thermal model had developed to notice effects of melting. This study focused heat transfer progression. The thermal characteristics of materials, such as conductivity and heat capacity, are the temperature dependent. Moreover, the workpiece structure changes over time, the heat dissipation during sintering unlike [10]. Erik R. Denlinger et.al uses 3D thick plate with base plate modelling where they use thermo mechanical modelling is procedure of transient thermal is coupled to static structural which result thermal and stress results [11]. S. Pereira et.al describes the direction build of the symmetric object which effect the deposition volume of material for each layer will be different for each orientation which effects the thermal and stress in an object [12].

A three-dimensional model is implemented for a tapered section with a geometry (30 mm x30 mm x30 mm) in three orientations, this allows to see the fluctuation in temperature distribution, tension, and deformation in three components. Orientation and geometry are the two objectives that influence the temperature distribution and residual stress. The orientation of part is more effective because of volume deposition of material for each layer in each orientation being varied, so because of alter in volume deposited, thermal stresses will be persuaded in object, it causes distortion in the part. The unsymmetrical geometry of a tapered section is considered for the modelling because the varying of dimension compared to symmetric geometry. As a result, temperature profile is affected by the difference in dimension of the section from root to tip.

II. MATERIALS

The metal alloy is used for the building of parts is maraging steel in this work. The alloys are the lightweight particles which uses laser as the source which it melts the alloy and the solidification takes place. The thermal conductivity, thermal expansion, are the thermal properties which effects the thermal conditions of the part geometry. Mechanical characteristics like young's modulus, bulk modulus etc. which effect the stress in the part.

Table 1: Composition of maraging steel

Elements	**Composition (wt%)**
Carbon	0.03
Silicon	0.10
Manganese	0.10
Prosperous + Sulphur	0.010
Nickel	18.00-19.00
Cobalt	8.50-9.50
Molybdenum	4.70-5.20
Titanium	0.50-0.70
Aluminium	0.05-0.15

III. GEOMETRY

The three-dimensional component is modeled of unsymmetrical section of tapered section with two holes the dimensions of (30mm×30mm×30mm) and the dimension of each hole is 6mm diameter which is effective because of varying dimensions from bottom to top when collate with symmetric part. The component is simulated in three orientations. The tapered section is chosen to simulate because the effectiveness of stresses will more in this geometry due to the orientation when compared to symmetric part the Figures 1,2(a) and 2(b) represents the three components are modeled in thermo mechanical procedure. The parts are divided into layers where the inputs are applied to layers to notice the variations in the Thermo-Mechanical Modelling.

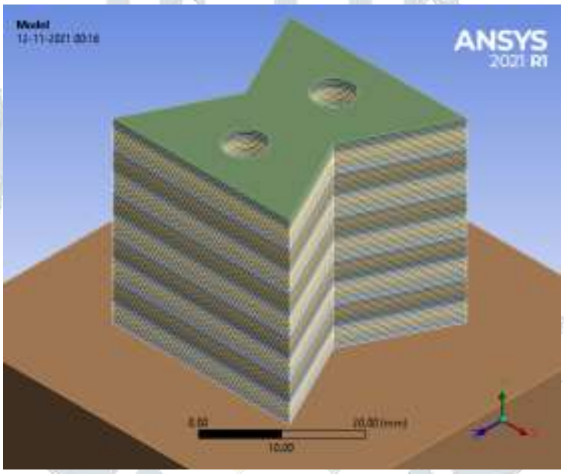
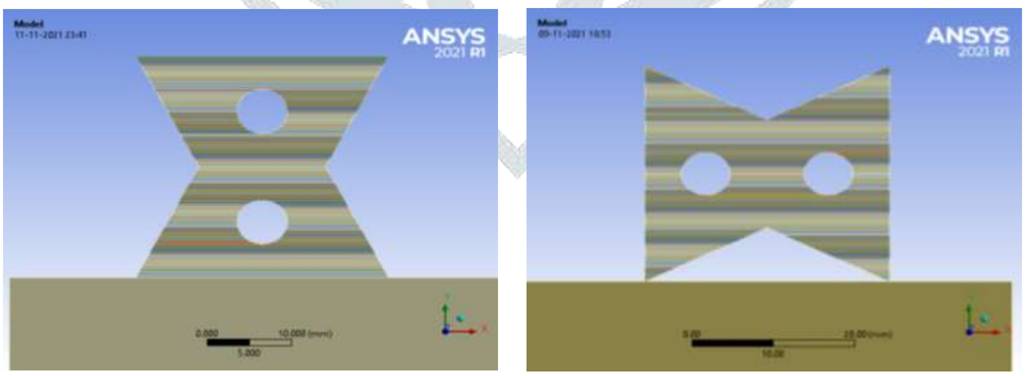


Figure 1: First Sample



(a) (b)

Figure 2: (a) Second sample (b) Third sample

IV. THERMAL MODELING

The three-dimensional component of tapered section with dimensions of (30mmx30mmx30mm) is analyzed in three orientations to notice the thermal and static results in three directions. The thermo mechanical modelling is technique where the Figure 3 represents the process of modelling. in this technique, transient thermal is coupled with static structural which is done in ANSYS software. The properties like thermal conductivity, specific heat, thermal expansion are the characteristics of material where the thermal boundaries are input to transient thermal model, the results of transient thermal is the input to the static structural which results von-misses stresses, deformation

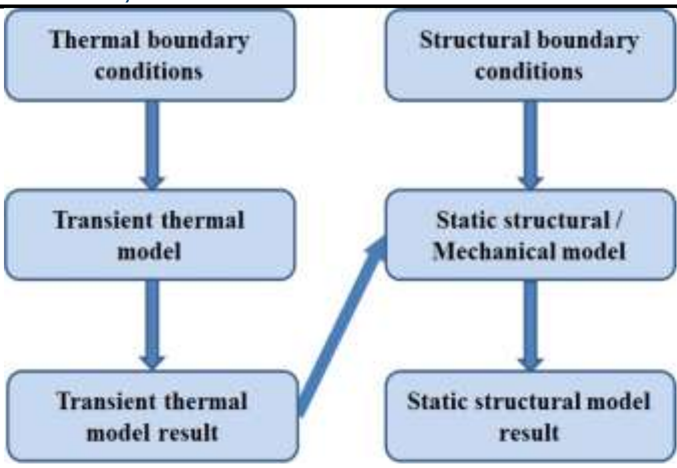


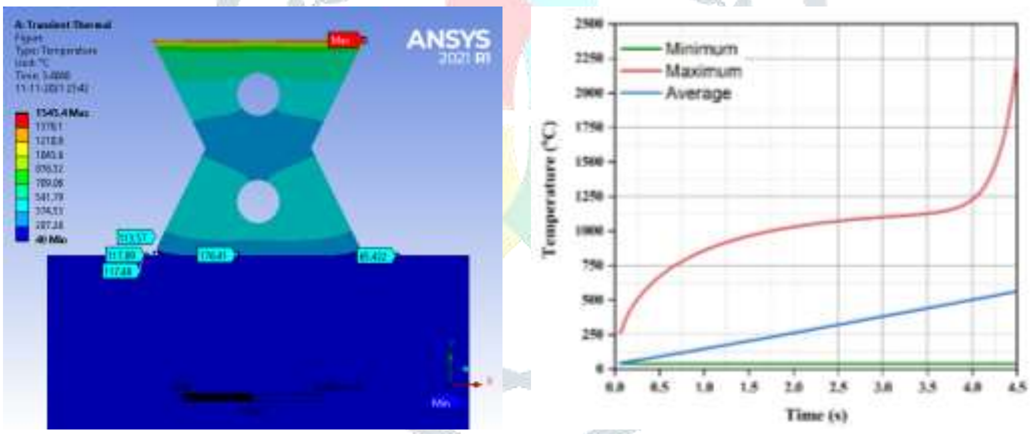
Figure 3: Flow chart of thermo mechanical process

V. SIMULATION RESULTS

The thermo mechanical modelling is developed in Ansys tool with the geometry of (30mm x 30mm x 30mm) in three directions of tapered section to turnout the temperature and residual stress generation of the component. The scope of simulating the same section in three direction is to detect the thermal stress which are persuade in the parts. Because of direction variation of part, the depositing volume for each layer will vary for each part. in relative to volume deposition for each layer, the heat dissipation of parts will variate where only the conduction heat transfer takes place but no convection. Because of conduction mode, heat dissipation is less. The heat will accumulate in each layer which lead to residual stress. To observe the residual stress for three orientation simulation should be required. The thermo mechanical modelling is developed in Ansys software to develop thermal distribution and residual stress.

5.1 First Orientation

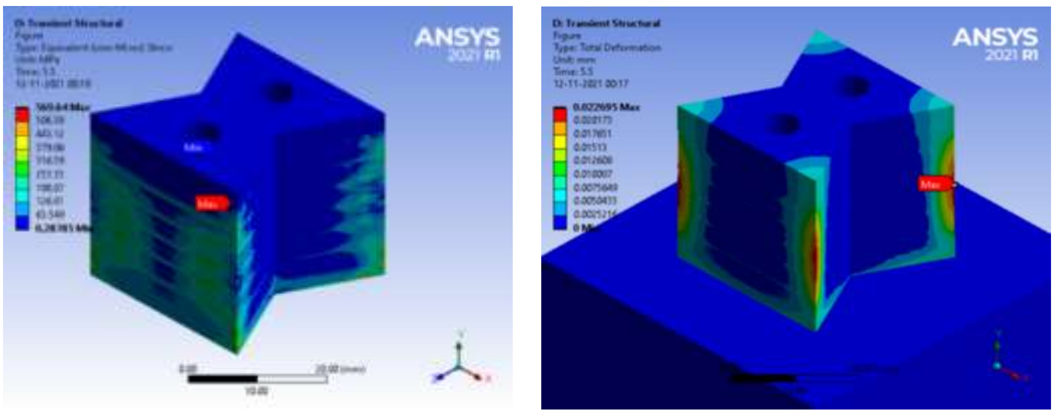
The component is simulated with assist of Ansys tool to generate the first orientation. the thermal modelling is simulated in transient thermal then the temperature is developed. Below Figure 4(a) illustrates the temperature distribution of the first orientation. The maximum temperature is 2238.9ºC. the temperature is high because the volume deposition rate is constant from bottom to top. Because of same volume rate, only the conduction takes place, so heat dissipation is less. The Figure 4(b) illustrates the temperature vs time graph.



(a) (b)

Figure 4: (a) Temperature Distribution of First Sample (b) Temperature vs. Time Graph

The below Figure 5(a) and 5(b) tells results of static-structural where the residual stress and deformation are resulted with input of thermal outputs. The maximum von misses stress in first orientation is 569.64MP. The deformation of the first orientation is 0.022695mm.

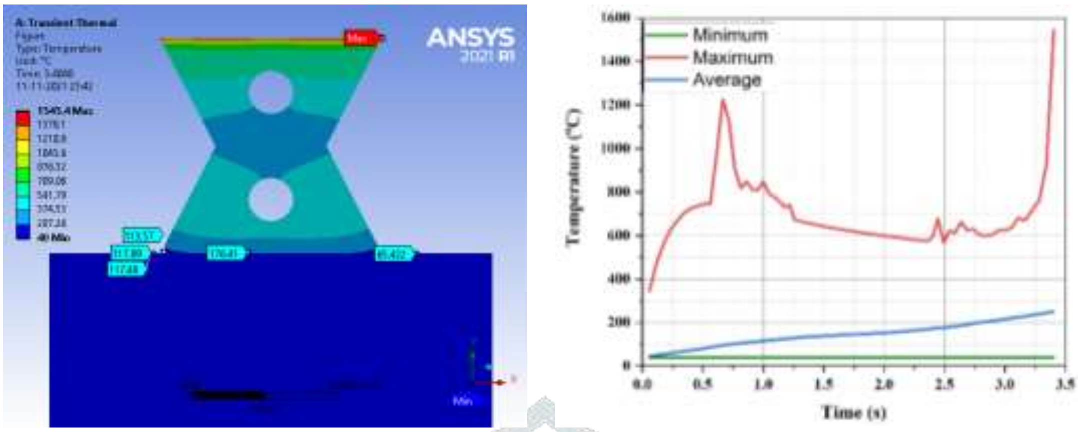


(a) (b)

Figure 5: (a) Von-Misses stress of First Sample (b) Deformation of First Sample

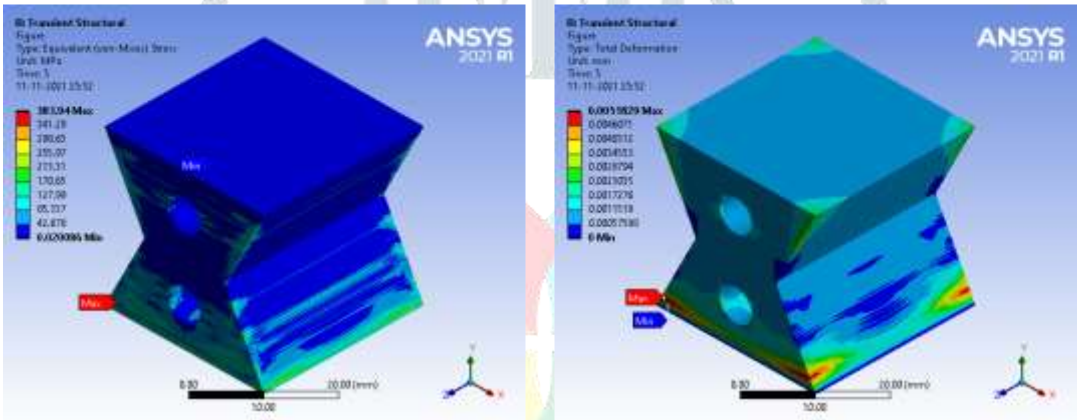
5.2 Second Orientation

In this orientation, the part dimension will vary from bottom to top where the temperature will fluctuate when contrast to the first orientation. The residual stress also vary because the volume deposition of material is different but not constant. The below Figure 6(a) show the temperature distribution of the part where the highest temperature is 1545.4ºC.the Figure 6(b) is graph represents the temperature vs time. The Figure 7(a) illustrates the von-misses stresses formation with 383.94 MPa, the Figure 7(b) describes about the deformation with 0.0051829mm



(a) (b)

Figure 6: (a) Temperature Distribution of Second Sample (b) Temperature vs. Time Graph

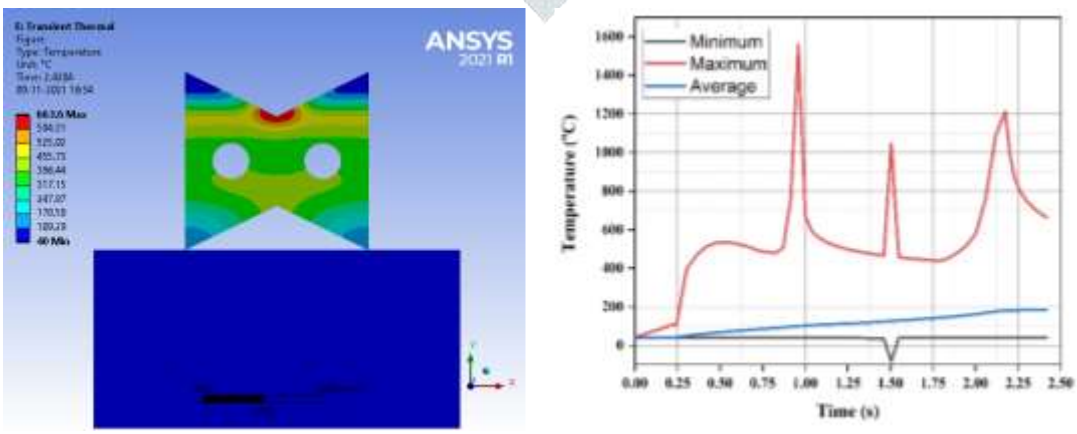


(a) (b)

Figure 7: (a) Von-Misses Stress of Second Sample (b) Deformation of Second Sample

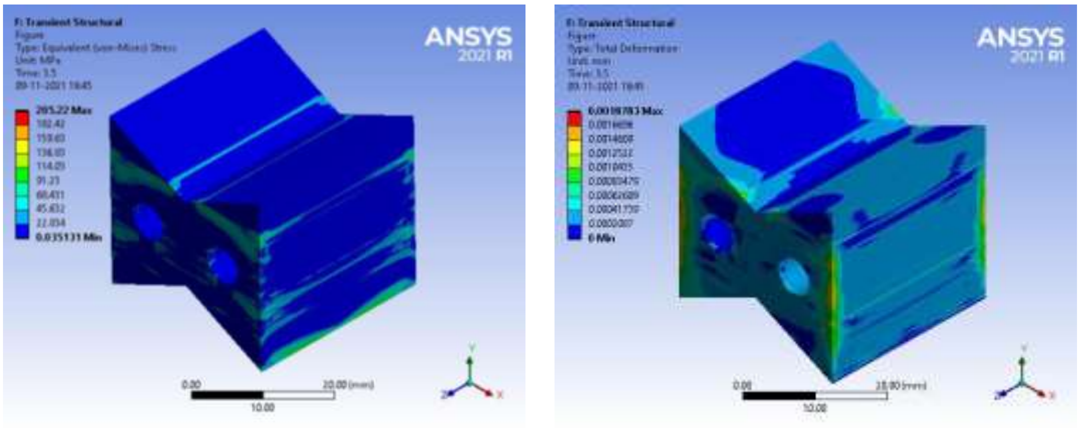
5.3 Third Orientation

In this orientation the deposition of volume is less when contrast to remaining orientations. in this simulation, the heat dissipation is more when collate to other parts because less material addition of volume. So, the temperature distribution and stress formation are less obtained when differentiate with other orientation. Below Figure 8(a) shows the temperature distribution with the temperature of 663.6ºC, Figure 8(b) The graph representation the temperature vs time, Figure 9(a) von-misses stress formation with maximum of 205.22MPa, and Figure 9(b) deformation with 0.0018783mm.



(a) (b)

Figure 8: (a) Temperature Distribution of Third Sample (b) Temperature vs. Time Graph



(a) (b)

Figure 9: (a) Von-Misses stress of Third Sample (b) Deformation of Third Sample

VI. CONCLUSION

Additive manufacturing is a material addition technology for creating complex parts. The metal components are usually created with additive process but the flaw is distortion, warping, etc. In research, the motive is to notice the residual stress generation and temperature distribution in each orientation because of volume deposition rate changes in each orientation the stresses are induced which yields dimensional inaccuracy of the part.

- In the first orientation the temperature of 2238.9◦C is more because of volume deposition rate is same from bottom to top which results to low heat transfer when collated to second and third orientations with the temperatures of 1545.4◦C and 663.6◦C.
- The residual stress is the limitation which outcomes to distortion. The first orientation got a highest residual stress of 569.64MPa when compete to second and third orientation stresses of 383.94MPa and 205.22MPa.

In future research, the thermal modelling and fabrication can be validating the temperature and residual stresses for a complex component in different orientation

VII. ACKNOWLEDGMENT

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