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Formability studies on Ni-Ti shape memory alloy using laser forming technology

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Abstract. Laser forming is an advanced manufacturing process which is extensively used in automotive and manufacturing industry by deforming metallic and non-metallic sheets. In this process, a continuous fiber laser is irradiated over Ni-Ti sheet. As the laser beam imbibed over the sheet, a step temperature thermal gradient got induced across the thickness of the sheet. The bending moment arises due to uneven thermal stresses leads to the deformation of the sheet without using any external forces. This paper shows the experiments performed on Ni-Ti sheets of dimension 60mm×50mm with a maximum power of 50W. The process parameters which were varied are number of passes (10 to 20), power (30W to 50W) to get the maximum bending angle with a uniform spot diameter of 2mm. The study between variations of the bending angle with process parameters is done. After this, the characterization of samples was done using differential scanning calorimeter (DSC) and the changes in phase transformation of Ni-Ti SMA with respect to change in different powers and number of passes is studied.

1. Introduction

Shape memory alloy (SMA) is a class of smart material which is known for two distinct properties such as superelasticity (SE) and thermal shape memory effect (SME). SMAs have the ability to achieve high deformation and return to a certain predefined shape upon unloading or after heating above a certain temperature. SME refers to the phenomena where the SMA will automatically come to its original position after heating and SE is the effect where SMAs may undergo huge non-linear deformation and comes back to its original shape upon unloading. Due to these amusing properties, SMA's have found various applications in the region of biomedical field as well as in industrial sector such as for making fasteners, coupling, actuators, etc.[1-3]

SME can be seen in various alloys such as Cu-Zn-Al, Cu-Al-Ni, Nb-Ti, Cu-Sn, Ni-Ti, Ti-Nb, Cu-Al-Be. Among the various options, Ni-Ti alloys are being widely used because of its ability to retain SME and practicability for longer time [4-5]. They are light in weight, corrosion resistance and have excellent fatigue resistance with low stiffness due to which they show high performance and thus are widely used in MEMS field.

Laser forming is an advanced manufacturing technique which has been developed during recent years. It is an advanced unconventional forming technique used for deforming metallic and non-metallic sheets. The forming of sheets generally occurs due to the induction of non-uniform thermal stresses. When a high power beam is irradiated on the surface of sheet, it leads to the generation of thermal compressive stresses peculiarly near to the irradiated area. The heated area of the workpiece will get expanded but because of the resistance from the surrounding material, localized plastic deformation occurs. The surrounded area of the heated region will remain in the elastic state and upon cooling this region under tension, bending of the workpiece takes place [6-8]. The laser line beam's power, spot diameter, marking speed and number of passes will determine the final pattern of the workpiece.

This technique is more advantageous than other unconventional techniques as it requires no external force, due to which spring back can be negligible [9]. It is a non-contact process by which complex parts can be easily formed. Also, this technique is mostly used nowadays for the fabrication of very small complex parts as this method involves less cycle time and moreover it eliminates the need for expensive dies.

This work focuses on the laser forming of Ni-Ti SMA sheet. A detailed investigation has been carried out to find out the corollary of laser parameters such as power and number of passes on the bending angle of Ni-Ti sheet. In addition, the outcome of forming parameters over the phase transformation behaviour of the laser irradiated area of the Ni-Ti sheets has been analyzed using differential scanning calorimeter (DSC) [10].

2. Method of experiments

2.1 Experimental setup

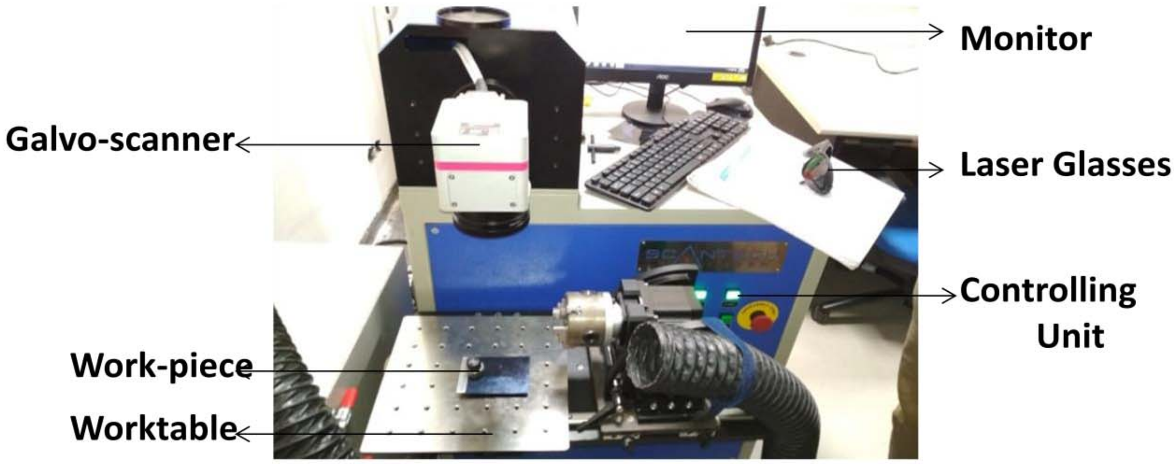

Figure1 – Experimental setup used for laser forming

A fiber laser (Scantech laser Pvt. Ltd) doped with rare earth elements like erbium, ytterbium, neodymium, etc is used in our case. It has a rated capacity of 50 W with a galvo scanner which deflects the beam in X

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and Y direction with a focal length of 160mm. The Ni-Ti sheet of dimension 60×50×0.25 mm is used in our experiments. The sheet is clamped at one end of the worktable as shown in Figure1.

2.2 Experimental procedure
Firstly the parameters of the laser such as power, spot diameter, mark speed and number of passes were fixed. The laser line beam is then marked at a distance of 20 mm from the extreme end with the help of scanmark software. Now the laser line beam is irradiated on the surface of the Ni-Ti sheet as shown in figure2. The forward and the backward stroke are considered as one single pass. The sheets were scanned for the different number of passes in order to get the maximum bending of sheets. The different laser and process parameters affect the bending angle. The parameters which were varied are Power (30W to 50W), Number of passes (10 to 30). There is no time lapse given between each pass. A total of 6 Ni-Ti samples were bent having a thickness of 0.25mm as shown in figure3. Here the spot diameter is kept 2mm for all the samples.

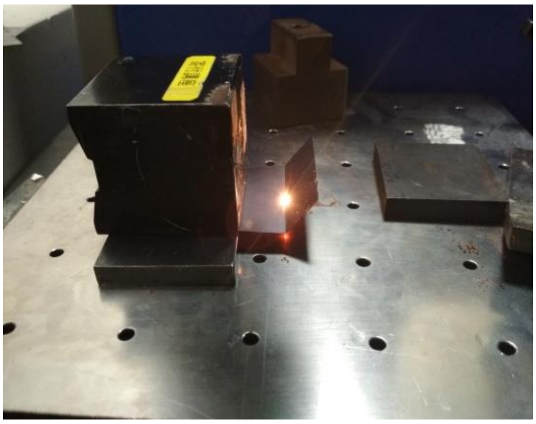

Figure2 - Irradiation of laser on the Ni-Ti sheet.

Figure3 – Bended Ni-Ti samples after laser irradiation

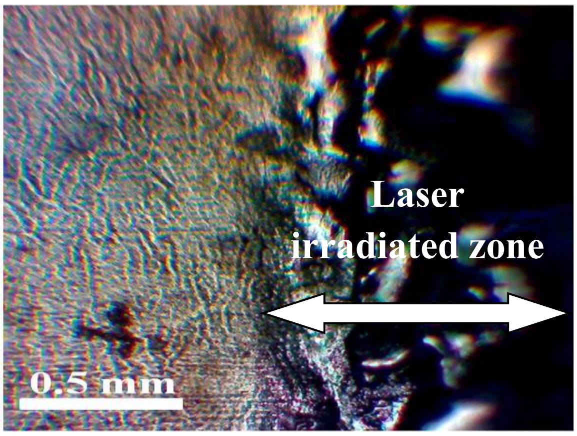

Figure4 - Microscopic image of Formed Sheet

After the laser processing of all the samples, their bending angles were measured manually. Also, the samples were sectioned for the DSC analysis so as investigate the phase transformation of Nitinol (Ni-Ti) with respect to the variation in power and number of passes.

3. Results and discussion

The deviation of bending angle with respect to power and number of passes are discussed in this chapter. Also, the phase transformation behaviour of the Ni-Ti samples with respect to the change in process parameters is also analyzed.

3.1 Parametric Analysis

A non-linear relationship can be seen between the bending angle and power. As the power is increased, the bending angle also gets increased due to the generation of more thermal compressive stresses on the irradiated area. But after a certain time, the increment in the angle is not so steeper because of the decrement of the thermal extension and plastic deformation of the irradiated surface. It indicates that there is an optimal temperature after which there is no such large variation in the increment of the bending angle.

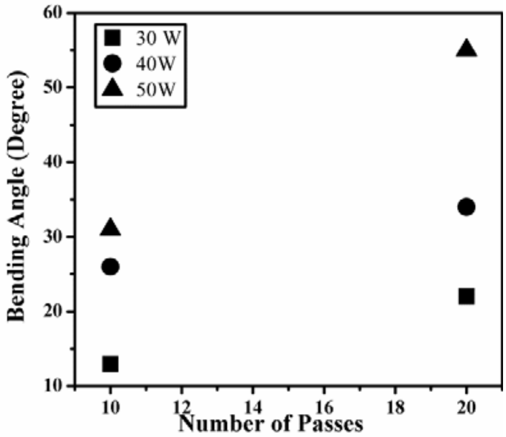

Figure5- Bending angle variation with number of passes

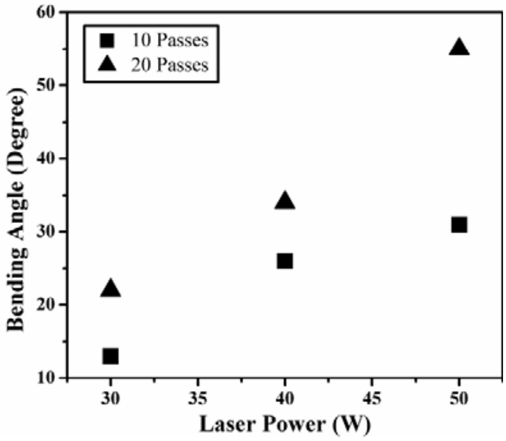

Figure6- Bending angle variations with power

Figure5 shows the variations in the bending angle with reference to the number of passes for three different laser powers 30W, 40W and 50W.Whereas figure6 shows the change in the bending angle with reference to power at two different number of passes i.e. 10 and 20 passes. It can be noticed that power and number of passes are the two important parameters which are affecting the bending angle of the sheet. With the increase of laser power and the number of passes the thermal compressive stresses will increase and leads to thermo-mechanical effects over the sheets due to which the bending angle increases. The increase in the compressive stresses leads to more plastification of the irradiated surface and thermal expansion to the opposite side of the sheet leading to more forming of the desired sheet.

3.2 DSC analysis

Figure7 shows the differential scanning caliometry curves of Ni-Ti sheet for 30W power at two different passes i.e. 10 and 20. It can be clearly seen from the DSC curves that there is a significant single stage transformation seen in both the heating and cooling curves. The Austenite start temperatures are (A_s) = -52.5ºC and -50.9ºC whereas the austenite finish temperatures are (A_f) = -32.6ºC and -33.2ºC. Also in the cooling curve the martensite start are (M_s) = -71ºC and -70.7ºC whereas the martensite finish temperatures are (M_f) = -100.9ºC and -94.4ºC. During heating, martensite will transform into austenite and while cooling austenite will transform into martensite.

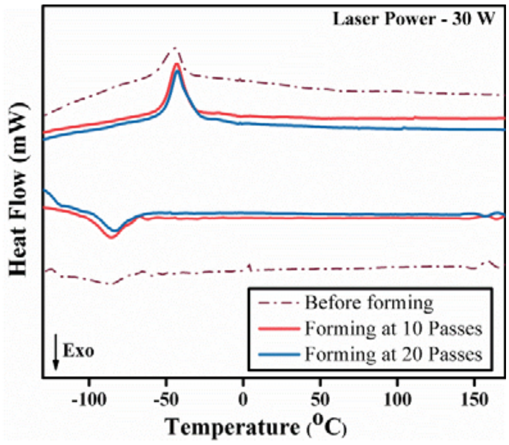

Figure7- DSC curves at 30 W power

Figure8 shows the DSC curves of the Ni-Ti sheet at 40W for 10 and 20 numbers of passes. Here the Austenite start temperatures are (A_s) = -52ºC and -52.1ºC whereas the austenite finish temperatures are (A_f) = -35.8ºC and -19.4ºC. Also in the cooling curve the martensite start are (M_s) = -74.8ºC and -50.2ºC whereas the martensite finish temperatures are (M_f) = -97.8ºC and -101.1ºC. The curves in both the heating and cooling curves are clearly noticeable. Here, there is a single stage transformation in the Ni-Ti SMA only for 10 passes while for 20 passes there is a two-stage transformation in the Ni-Ti due to the generation of R-phase in the material [7].

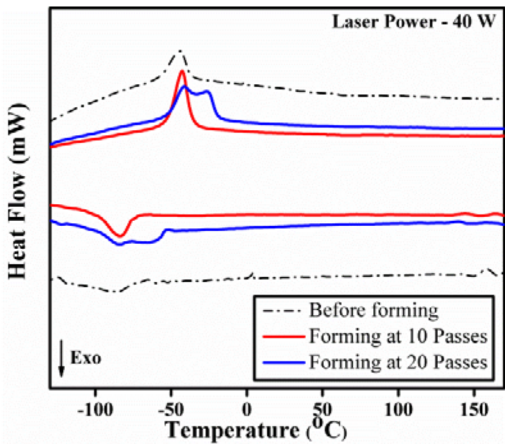

Figure8- DSC curves at 40 W power

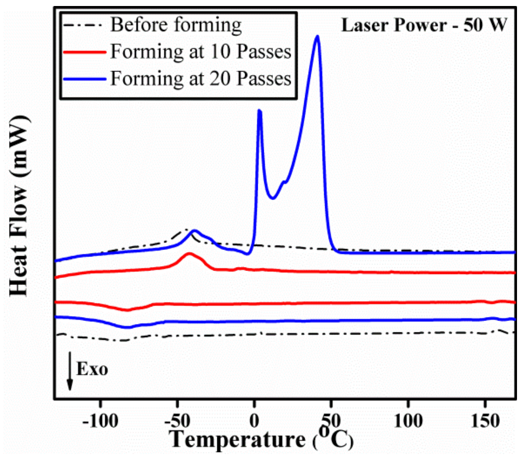

Figure9- DSC curves at 50 W power

Figure9 shows the DSC curves of Ni-Ti sheet for 50W power at two different passes i.e. 10 and 20. The austenite start(A_s) temperatures for 10 and 20 passes are -53.7ºC and 0.4ºC whereas austenite finish(A_f) temperatures are -28.9ºC and 47ºC, likewise martensite start(M_s) temperatures are -65.3ºC and -58.7ºC and martensite finish(M_f) temperatures are -103ºC and -103.9ºC.Here also we see can that for 10 number of passes there is only a single stage transformation in the Ni-Ti SMA while for 20 number of passes there is a two-stage transformation due to the generation of R-phase which entail that with the increase in laser power and number of passes, the forward transformation has changed from one stage to two stage.

4. Conclusion

In current work laser forming on Ni-Ti sheets of 0.25 mm were performed. The variation in the bending angles with respect to the process parameters were calculated and it is found that there is a certain non-linear increment in the bending angle with an increment of power and number of passes. The DSC analysis done for the samples also gives the idea that there is only a single stage transformation in the Ni-Ti SMA for 30W laser power in 10 and 20 passes while for 40W and 50W laser power there is a two stage phase transformation occurs due to the generation of R-phase.

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References

[1] Birnbaum A and Yao Y 2010 *Journal of Manufacturing Science and Engineering* **132** p 041002
[2] Wu H and Schetky L 2000 *International Conference on Shape Memory and Superelastic Technolgies* **182** pp 171-82
[3] Lagoudas D 2010 *Shape Memory Alloys: Modeling and Engineering Applications* (Texas: Springer)
[4] Shiva S, Palani I, Mishra S, Paul C and Kukreja L 2015 *Optics and Laser Technology* **69** pp 44-51
[5] Wang W, Chen L and Zhao X 2008 *3rd Pacific International Conference on Applications of Lasers and Optics, PICALO 2008* **31** pp 162-86
[6] Singh S, Gautam S and Dixit U 2014 AIMTDR 2014
[7] Paunoiu V, Squeo E, Quadrini F, Gheorghies C and Nicoara D 2008 *International Journal of Material Forming* **1** pp 1371-74
[8] D'Souza A, Palani I and Naikwad S 2015 RACE 2015
[9] Shi Y, Yao Z, Shen H and Hu J 2006 Int. J. Mach. Tools Manuf. **46** pp 1689-97
[10] Duerig T and Bhattacharya K 2015 *Shap. Mem. Superelasticity* **1** pp 153-61