Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2016/02/jls.htm
2016 Vol. 6 (S3), pp.50-57/Lotfi Shahpar
Research Article

EXPERIMENTAL ANALYZING EFFECTS OF LASER ASSISTED FORMING PARAMETERS ON FATIGUE RESISTANCE OF ALLOY STEEL INCONEL 617

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ABSTRACT
In current article, effects of laser assisted forming parameters on fatigue resistance of alloy steel Inconel 617 is studied experimental. Laser power and laser scan speed are selected respectively in 800, 1200, 1500 W and 0.5, 1, 1.5 m per minute to do experiments and the fatigue test is used to determine fatigue life. Results show the maximum fatigue resistance is in power of 1500 W and scan speed of 0.5 m per minute. Increasing roughness of surface, fatigue resistance is decreasing. Also fatigue resistance of samples with minimum roughness of surface is achieved about 3 to 5 times more than fatigue resistance of sample with the maximum roughness of surface.

Keywords: *Laser Assisted Forming, Fatigue Resistance, Roughness of Surface*

INTRODUCTION
Alloy steel Inconel 617 is applicable in manufacturing of gears, axels and slider critical pieces that need high abrasion resistance. Percent of manganese and chromium in alloy steel increases harden ability and improves abrasion resistance. Manganese according to percent of carbon steel increase strength steel and decreases its vulnerability. Due to high hardness and resistance of steel, one of the processes to form the used piece is laser assisted forming (Singh *et al.,* 2011; Abbas *et al.,* 2007). Since this mechanism in laser assisted forming is done electro thermally, it causes creating fuzzy and microscopic modifications and some cracks on the forming surface (Casas *et al.,* 2006; Kumar *et al.,* 2009). Rajendran *et al.,* (2013) found that Laser power has a direct relationship with density of cracks on the surface. These cracks were concentration points of stress in loadings and were factors of decreasing fatigue resistance of pieces. Abhay *et al.,* (2010) understood increasing fatigue life is related to surface quality in these steels and adding powder to liquid dielectric can increase roughness of surface and consequently, it can increase fatigue resistance. Lee and Tai (2003) considered two parameters, Laser power and laser scan speed being on, as variables and are used D2 and H13 steels as work piece. They understood increasing these two parameters increase density of cracks that is the main factor of decreasing fatigue resistance. Following their study, Tai and Lu (2009) people announced that pre stress and polishing surface can significantly increase power of fatigue resistance. Zeid (1997) understood increasing crake value on the surface of forming piece by laser assisted forming, laser assisted forming resistance decrease. Also he founded increase in hardness value on the forming surface by the laser assisted forming and reported increasing carbon value existing on the surface as its factor. Mower (2014) reported laser assisted forming method decreases fatigue life of pieces that its reason is starting crack in HAZ region resulting from laser assisted forming process. Kiyak *et al.,* (2007) studied effects of forming parameters such as laser scan speed being on, laser scan speed being off and Laser power on quality of 40CrMnNiMo864 steel surface and founded increasing laser scan speed being off and decreasing both time of Laser power and laser scan speed being on increase quality of surface. Guu *et al.,* (2007) understood effects of laser scan speed being off on structure and quality of surface is more than Laser power. Xu *et al.,* (2013) understood fatigue is function of heat affected region that its depth and dimension must be controlled by controlling Laser power. According to conducted researches, one of the most important factors in decreasing fatigue resistance of steels is roughness value of forming surface. Studying density of cracks resulting from laser assisted forming in heat affected region is considered important to determine fatigue life of pieces. In this way,

current research, conducting experimental researches in different levels of laser scan speed being on and Laser power, studied effect of parameters in laser assisted forming on fatigue resistance of steel Inconel 617.

MATERIALS AND METHODS

Material and Research Methods

Alloy steel Inconel 617 is selected as a material of piece work that its chemical composition and mechanical properties are shown in table 1 and 2. Dimension and shapes of samples are shown in figure 1 and figure 2 based on the used sample standard in fatigue test.

Table 1: Chemical Composition (Weight %) of Alloy Steel Inconel 617

Name of Elements	Percent of Elements (%)
C	0.05-0.15
Si	1
Mn	1
P	0-0.025
S	0.015
Cr	20-24

Table 2: Mechanical Properties of Alloy Steel Inconel 617

Mechanical Properties	Value (MPa)
Tensile Strength	734-769
Final Yield Stress	318-383
Strain	15%

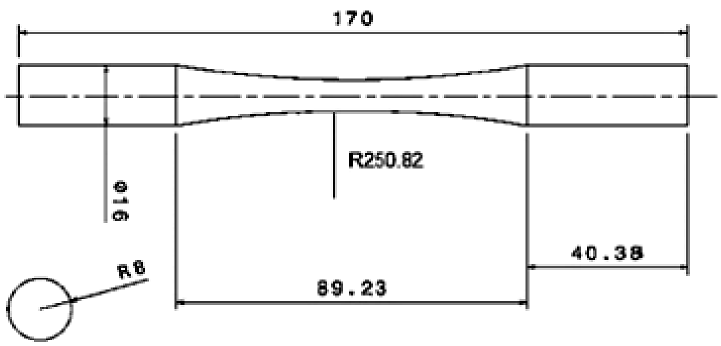

Figure 1: Geometry and Dimension (mm) of Fatigue Specimen

Figure 2: (A) Prepared Steel Specimen for Fatigue Test; (B) Copper Electrode that Used for Forming

Laser power and laser scan speed being off are used in forming of each in 3 levels are shown in table 3. To more accuracy, machining has been done in each level with 3 repetitions. Status of specimens machined by optical microscope is studied with magnification of 200 times. To do fatigue test, System Moore fatigue test is made as shown in figure 3. The made System Moore fatigue test is able to complete full reversal stress in 50-800 MPa in the rotational speed 500-3000 rpm. Specimens are tested under 360 MPa stress and below tensile strength of this kind of steel and in standard frequency of Moore fatigue test, that is, 1750 rpm. Also roughness of each specimen's surface produced by Perthometer roughness measuring device is measured along with 5.6mm benchmark. Finally, some images of cross-section of work pieces is provided by scanning electron microscopy (SEM) to determine thickness of HAZ layer and density of cracks.

Table 3: Laser Parameters Used for Examination

N	Laser Scan Speed V(m/min)	Laser Power P(w)
1	0.5	800
2	1	800
3	1.5	800
4	0.5	1200
5	1	1200
6	1.5	1200
7	0.5	1500
8	1	1500
9	1.5	1500

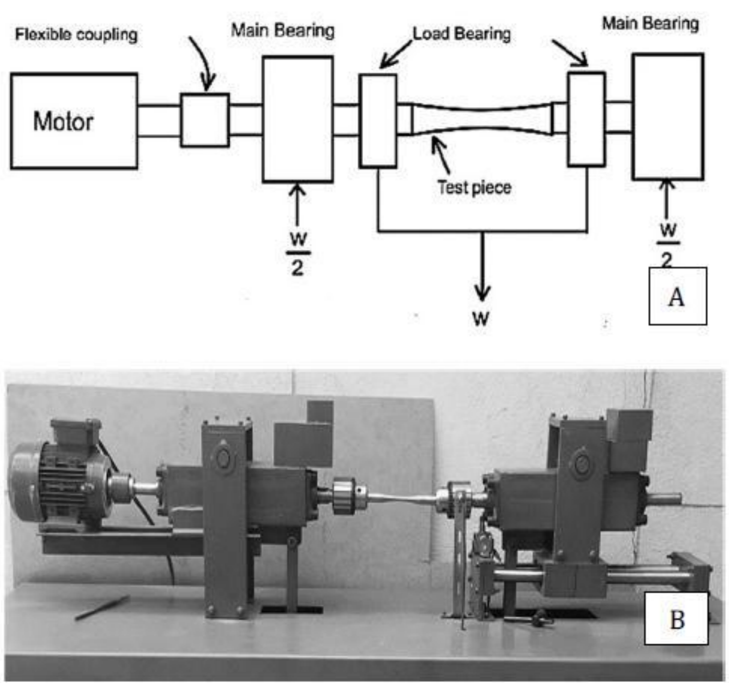

Figure 3: Fatigue Test Machine (A) Schematic View; (B) Actual View

RESULTS AND DISCUSSION

Effects of Laser Power on Density of Cracks in Heat Effected Region and Fatigue Resistance of Alloy Steel Inconel 617

Figure 4 shows the relationship between Laser power and fatigue resistance of alloy steel Inconel 617, it is obvious that increasing Laser power decrease fatigue resistance. Its reason can be justified as increasing spark energy by increasing laser assisted forming parameters such as Laser power increases thermal energy enters into surface as well as it causes increasing thickness of heat effected layer (Zeid, 1997) and (Merdan and Arnell, 1989). Electron microscope images of fracture surface of specimen are shown in figure 5. Prepared images obviously shows thickness of heat effected region as well as high density cracks by increasing Laser power in this region. Heat effected region has a reminded tension in its structure due to melting and then fast freezing resulting from dielectric fluid that is a formation factor of micro cracks and surface defects in forming pieces by laser assisted forming method (Merdan and Arnell, 1989) and (Xu *et al.*, 2013). Studies reveal that cracks of fatigue in forming pieces by laser assisted forming start from heat effected region and reach based steel that the high thickness of this layer, the high density and the more number of existing cracks on the surface. Growing cracks of fatigue is allowed and as a result fatigue resistance is decreased (Xu *et al.*, 2013).

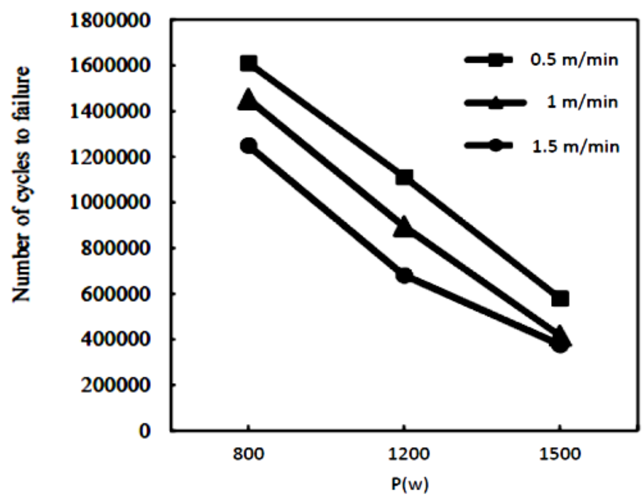

Figure 4: The Relationship between Laser Power and Fatigue Life of Alloy Steel Inconel 617 Samples

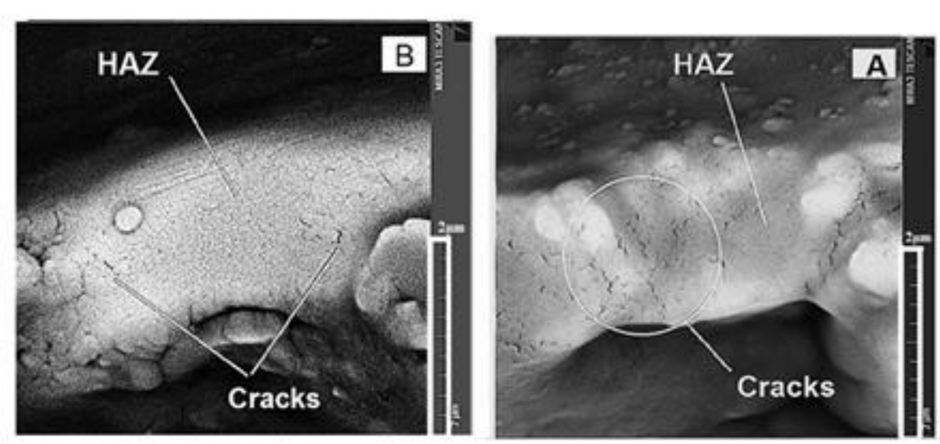

Figure 5: SEM Images Showing HAZ Region; (A) Image of Cross Section of Failure in Forming Piece with Laser Power 1500w and Laser Scan Speed 0.5m/min. (B) Image of Cross Section of Failure in Forming Piece with Laser Power 800w and Laser Scan 1.5m/min

Effects of Pulse Time on Thickness of Heat Effected Region and Fatigue Resistance of Inconel 617

Figure 6 shows relationship between laser scan speed and fatigue resistance of alloy steel Inconel 617, increasing laser scan speed decreases fatigue resistance of work pieces and cause fast cracks of fatigue.

The reason of this act can be justified as follows: the more increase in laser scan speed, the more opportunity to transfer thermal energy resulting from spark to the depth. Thickness of heat effected region is increased due to heating in a long term that is shown in scanning electron micrographs of figure 5. cracks of fatigue in forming pieces start from HAZ region by the laser assisted forming, reach based steel and result in final crack. The more thickness of HAZ layer, the more number of existing cracks on the surface followed by ideal setting to grow cracks of fatigue. As a result, fatigue resistance is decreased (Xu *et al.,* 2013).

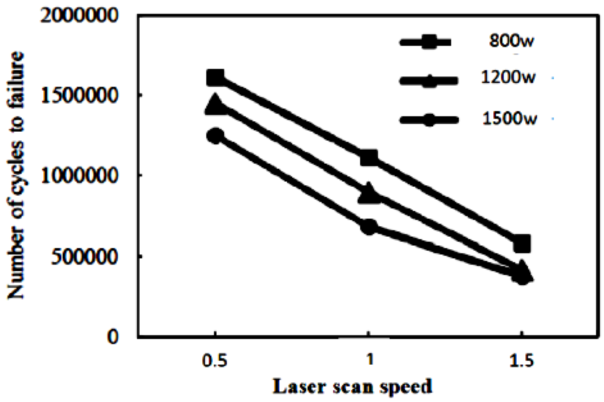

Figure 6: The Relationship between Laser Scan Speed and Fatigue Life of Alloy Steel Inconel 617

Effects of Laser Power and Laser Scan Speed on Roughness of Alloy Steel Inconel 617

Figure 7 shows relationship between forming parameters and roughness of alloy steel Inconel 617. It is obvious that increasing Laser power and Laser scan speed increases roughness of surface (Kiyak and Cakır, 2007). It is resulted from an issue that increasing forming parameters in forming by the laser assisted forming energy causes more sparks and as a result, melting volume is increased per pulse of spark. The greater amount of melt is thrown out by volumetric boiling that after freezing, makes deep holes more and thereby, roughness of forming pieces become more in laser assisted forming (Shabgard *et al.,* 2009). Figure 8 shows profile of the minimum roughness of surface in laser power of speed 800W and laser scanning of 1.5 m per minute and the maximum fatigue resistance is in power of 1500 W and laser scanning speed of 0.5 m per minute. The existing deep points in profile is a place of concentrated tension and also the first points are place of beginning micro cracks that play a significant role in decreasing fatigue resistance, increasing the depth of these holes makes inserted forces more concentrate on this point and cause acceleration in growth of cracks of fatigue (Guu and Hou, 2007).

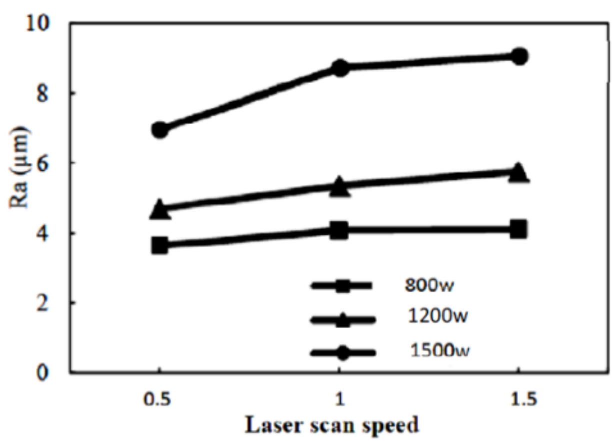

Figure 7: The Relationship between Laser Scan Speed and Roughness of Alloy Steel Inconel 617

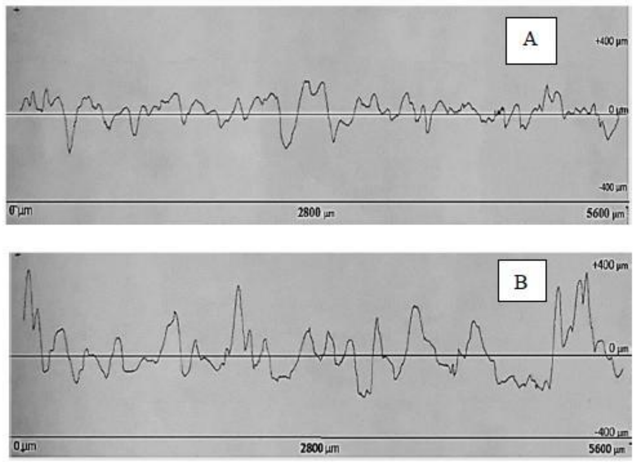

Figure 8: Roughness Profile of Specimen; (A) Sample Forming with Laser Power 800 and Laser Scan Speed 1.5m/min; (B) Sample Forming with Laser Power 1500w and Laser Scan Speed 0.5m/min

Comparing two cross section failures resulting from 2 moods of maximum and minimum roughness of surface concludes in the surfaces with minimum roughness, crack resulting from fatigue starts from one point that is place of growing the main crack but in surfaces with high density of crack and high roughness, crack resulting from fatigue starts from several points and causes more fast failure. This case is shown in figure 9. It seems the reason of this issue is existence of high density of crack and high depth of holes created after freezing in forming by the laser assisted forming method that result in having a surface with several concentration points, each point, in turn, is a separate place of growing crack and they play a significant role in decreasing fatigue resistance.

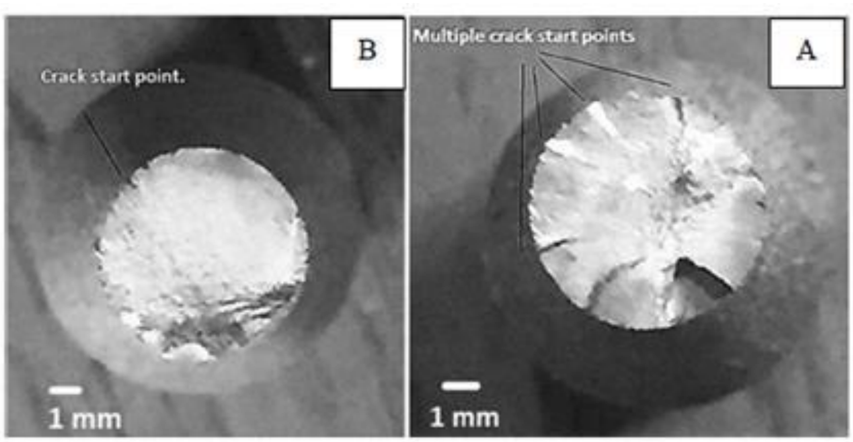

Figure 9: Cross Section of Samples after Fatigue; (A) Sample with Maximum Roughness; (B) Sample with Minimum Roughness

Effects of Roughness of Forming Surface by the Laser Assisted Forming on Fatigue Resistance of Alloy Steel Inconel 617

Table 4 shows the mean of fatigue resistance and the mean of roughness of alloy steel Inconel 617 after 3 repetitions in each surface of laser assisted forming. As you see, there is an inverse relationship between roughness of surface and fatigue resistance and increasing roughness of surface, forming surfaces get fatigue resistance (Abhay *et al.*, 2010) and (Tai and Lu, 2009). The reason of it can be cleared that failure resulting from fatigue in steel pieces has 2 stages. First stage is to create micro cracks on external and internal surfaces of pieces resulting from periodic loads and second stage is growth and spread of these cracks till results in fatigue failure. Since there is created surfaces by laser assisted forming along micro cracks (Zeid, 1997). Failure resulting from fatigue is restricted to one stage, that is, growth of crack, which causes decreasing fatigue life of pieces. Figure 10 is provided from optical microscope shows differences in density of crack in different forming settings which revels more density of crack in high spark energy.

Table 4: Results of Fatigue Life and Roughness in Different Settings

N	Fatigue Life(NF)	Roughness (µm)
1	1421090	4.454
2	1250815	3.070
3	1275486	3.109
4	1334143	3.705
5	794470	3.258
6	671411	4.854
7	569875	5.871
8	416520	7.820
9	389000	8.051

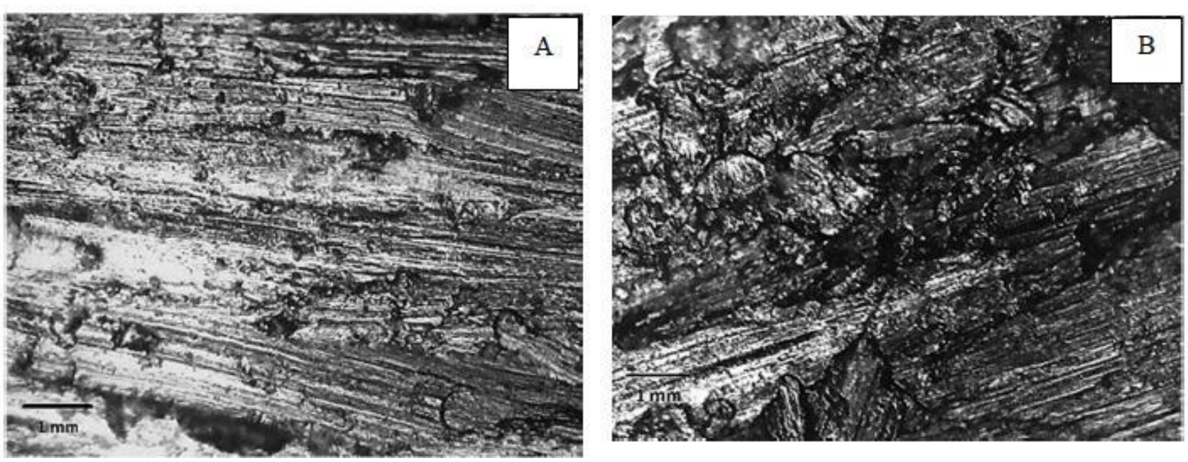

Figure 10: Optical Microscope Images of Laser Assisted Forming; (A) Sample with Laser Power 800w and Laser Scan Speed 1.5m/min; (B) Sample with Laser Power 1500w and Laser Scan Speed 0.5 m/min

Conclusion

In current research, effects of parameters in laser assisted forming on fatigue resistance of alloy steel Inconel 617 are studied experimentally and following results are obtained:

1. Increasing Laser power and laser scan speed decreases fatigue resistance of pieces.
2. The maximum resistance is related to laser power of speed 800W and laser scanning speed of 1.5 m per minute and the minimum one is related to laser power of 1500 W and laser scanning speed of 0.5 m per minute.
3. Increasing existing cracks on the surface of pieces and thickness of HAZ region decreases fatigue resistance.
4. Increasing roughness of pieces' surface decreases their fatigue resistance. According to differences of roughness in surface of specimens, fatigue resistance of specimens with the minimum roughness of surface is 3 to 5 times more than, fatigue resistance of specimens with the maximum roughness of surface.

ACKNOWLEDGEMENT
We are grateful to Jam petrochemical company for their useful collaboration.

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