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INVESTIGATION OF EFFECT OF GRAIN SIZE ON THE MECHANICAL PROPERTIES OF AL ALLOY BY USING FRICTION STIR HOLE EXPANSION

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ABSTRACT

The aim of the research work was to investigate on the effect of Friction stirring of a fastener hole affects the surface and mechanical properties of the hole. The surface that was friction stirred had the same roughness as that of the drilled hole. The surface and mechanical properties affect the number of cycles sustained under fatigue loading. A typical gradient of these stresses along thehole axis is observed. The residual hoop stress distribution introduced by means of the alternative FSHE method decreases along the distance from the center of the increases. An axial residual hoop stress gradient is also observed, but to a lesser degree than mandrel cold working stress result. A new conception for increasing fatigue life of large number of fastener holes in aircraft structures is developed. It is accomplished by a new method, called friction stir hole expansion (FSHE).

KEYWORDS: Friction stir drilling, notch strain, notch stress, aluminium alloys, FSHE.SPD.

I. INTRODUCTION

Severe plastic deformation (SPD) is one of the methods of obtaining very fine crystalline structure in different bulk metals and alloys, which possess different crystallographic structure. SPD causes the formation of micrometer and sub-micrometer sized sub-grains in the initially coarse grain materials. As a result of that enhanced mechanical performance is observed.SPD is a procedure,whereby the structure of the material changes from the initial coarse grained state to ultra-fine grained structure. For the evolved microstructure is the ~70-500 nm average grain size characteristic.

The plastic working of metals and alloys at relatively low temperatures produces a hierarchy of dislocation substructures. The initial stages of straining introduce high dislocation densities, which are arranged in cellular substructures. An increase in strain is attended with localizations of plastic flow on a microscopic scale. The dislocation cells evolve into cell blocks that are subdivided by dense dislocation walls; these are essentially dislocation sub-boundaries whose miss orientations are appreciably larger than those of common cell walls. Then, various deformation bands begin to appear at medium strains that introduce still larger disorientations. This leads to the subdivision of the original grains into small, heavily disoriented fragments. This process of grain subdivision during deformation is fundamental to the process of grain refinement by SPD. The method of severe plastic deformation (SPD) is often used to produce bulk ultrafine grained materials. SPD is a procedure, whereby the structure of the material changes from the initial coarse grained state to ultra-fine grained structure. The method of severe plastic deformation (SPD) is often used to produce bulk ultra-fine grained materials (UFG). SPD is a procedure, whereby the structure of the material changes from the initial coarse grained state to ultra-fine grained structure.

The main technical problems are the same as in traditional metal forming operations. Thus one of them is the integrity of material deformed. Different materials show different deformation ability. The increased temperature may negate the structural effects of SPD by recovery and recrystallization and help in deformation of more brittle materials. Another problem related with increased processing temperature is flow softening of the material which may lead to plastic flow localization and to fracture.[8] The surface properties of the wall of cylindrical hole can be altered by friction stir processing using a specially designed tool that rotates while travelling through a cylindrical hole. This method can be applied to aerospace materials.[9] Cold expansion is used to induce compressive stress zone, by inserting a tapered mandrel/pin into an undersized fastener hole in order improve fatigue life.

II. MATERIALS AND METHODS

The experiments were conducted on a sensitive drilling machine available at the Machine Shop, which provides variable spindle speed and feed rate. The machine was used to drill a hole initially and attach Frictional Stir Severe Plastic Deformation tools as mentioned previously. The aluminum samples were clamped on the drilling bed and every sample as mentioned in the previous specification were done.

2.1 Preparation of Specimen:

The specimen used is of aluminum material which is cut according to the ASTM E 466-07 referring to the literature which specifies the dimension as shown in the Figure 2.

The design mentioned above is used to make specimen of nine numbers which is cut by cutter tool by hand. The specimen is made by using 5 mm aluminum sheet metal and finished by buffing on the edges. The specimen is as shown in the below Figure 3.

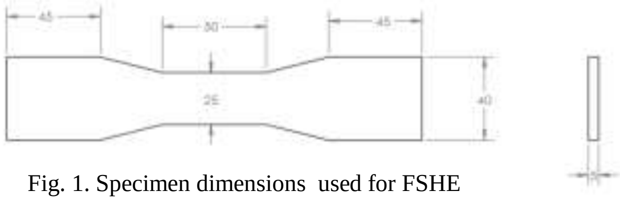

Fig. 1. Specimen dimensions used for FSHE

Fig. 2. Specimen dimensions used for FSHE

2.2 Manufacturing of the FSHE tool:

A Frictional Stir Hole Expansion (FSHE) tool made of HSS is used to enlarge the hole by frictional Stir Process which forms a plastic zone around the hole causing severe plastic deformation due to grain refinement. The tool design based on the information given in the literature and inputs fixed for obtaining SPD. The design is given as per the Figure 4.

The three tools are manufactured as per the below table for different values of $d_2$which in turn changes the taper in the tool increasing the friction in the contact surface

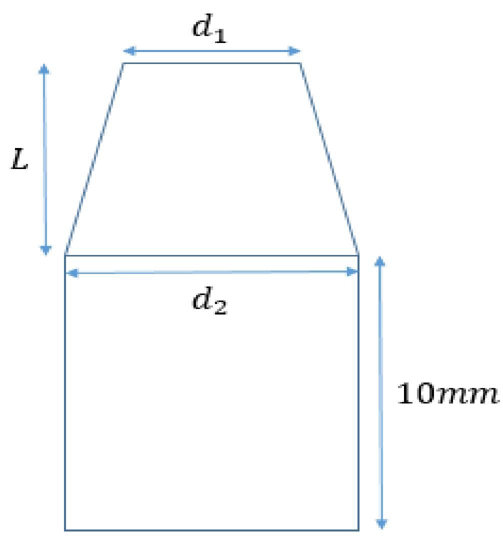

Fig. 3. Dimensions of the tool used for FSHE

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Table 1. Different specifications are used for FSHE tools

Tool number	**d_2 (mm)**	**d_1 (mm)**	**L (mm)**	**Taper angle (Deg)**
1	10.2	10.0	15	0.76
2	10.4	10.0	15	1.52
3	10.6	10.0	15	2.29

As per the above design consideration the three tools are manufactured by the process of grinding on a HSS cylinder of 12 mm diameter and 100 mm length as shown in the below figure.The taper is formed by the process of grinding for 15 mm from one end and it is grinded and end diameter as per the specification shown is grinded for another 15 mm without any taper.The remaining length is no grinded as retaining 12 mm diameter. The retained diameter of 12 mm is the part of the tool is held by the chuck of the collet.

Fig. 4. Different FSHE tools used for hole expansion

2.3 Sensitive drilling machine

As the definition goes about the sensitive drilling machine is that it adjust to minor adjustment. The sensitive drilling machine consist of the following parts mainly spindle, drive and worktable.

The drilling machine has both automated spindle speed and feed rate. The different spindle speed is required as to measure the effect on the SPD due to different speed. The method of obtaining the particular speed is by the combination as shown in the **fig** and speeds which are available are as follows600 rpm, 852 rpm, 1260 rpm, 1860 rpmand 2700 rpm. The speeds used in the experiments were limited to 600rpm, 852 rpm and 1260 rpm based on the literature SPD occurs.The method of obtaining the particular speed is having respective combination of belt drive which is as shown in the **Figure 6.** Similar to spindle speed even the effect of different feed rate has to be measured. In the Sensitive Drilling machine the feed rate can be varied a per the specification given which is shown in the below figure. The feed rate available in the Sensitive Drilling machine is 0.104 m/min, 0.211m/min, 0.315 m/min

Fig. 5. Sensitive Drilling Machine

The different feed rates are arranged based on the lever mechanism. Thus every specimen with particular feed rate is fixed as per the Taguchi method explained later to the particular reading and the operation is performed. The specimen is fixed on a worktable on which a wise clamped to the worktable with help of fasteners and the specimen are placed in between the jaws of the wise and tightened by screw mechanism. After the initial set ups as mentioned are done, the drill is fixed to the collet which assembled to the spindle of the drilling machine as an drill bit with Morse Taper (The shank of the drill is tapered which is according the standard called Morse Taper). Initially for every specimen a hole of 10 mm is drilled at the center by attaching the drill bit of HSS in the

Fig. 6. Drilling of specimen with FSHE tool

collet attached to the spindle to initially form by material. Later the drill bit is removed is and Frictional Stir Hole Expansion Tool is attached as per the taper mentioned for the particular specimen mentioned in the **table** as to obtain SPD by Frictional Stir Hole Expansion Process which expands the hole due to the frictional force between the tool and the specimen surface. The friction is more as the taper is increased. After the process of initial drilling and Frictional Stir Hole Expansion process done for nine samples as per the guidelines in the Table, the specimen were found as shown F**igure 7.**

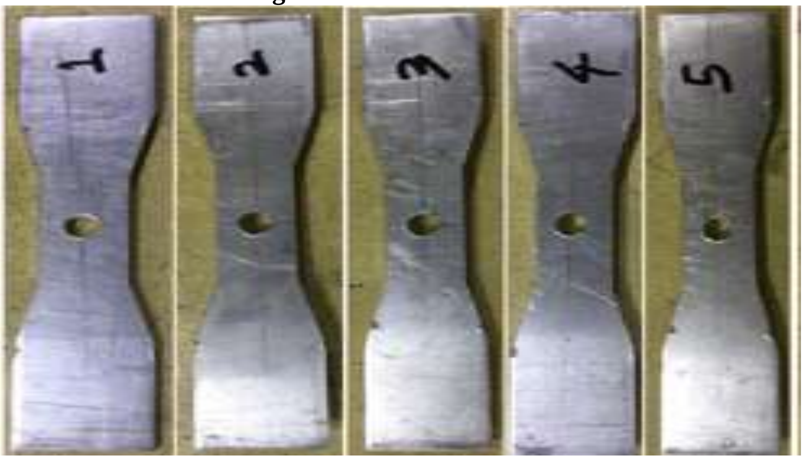

Fig. 7. Specimens after FSHE

2.4 Infrared thermometer

A laser pointer thermometer was used to measure the temperature of the specimen when the it undergoes frictional stir severe plastic deformation.The design essentially consists of a lens to focus the infrared thermal radiation on to a detector, which converts the radiant power to an electrical signal that can be displayed in units of temperature after being compensated for ambient temperature. This permits temperature measurement from a distance without contact with the object to be measured. A non-contact infrared thermometer is useful for measuring temperature under circumstances where thermocouples or other probe-type sensors cannot be used or do not produce accurate data for a variety of reasons. The laser pointer was pionted a the spot where enlargement of the holes are happening due firctional stir and the rise in temperature occur due to the friction between the tool and the specimen.

2.5 Design of experiment

Design of Experiment is a statistics-based approach to design experiments,methodology to achieve a predictive knowledge of a complex, multi-variable process with the fewest acceptable trials.An optimization of the experimental process itself.To achieve there are three methods.

- Factorial Design
- Taguchi Method
- Response Surface Design

2.5.1 Taguchi Method

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on " ORTHOGONAL ARRAY " experiments.This gives much reduced " variance " for the experiment with " optimum settings " of control parameters."Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments serve as objective functions for optimization. This menthod used uses the following steps to obtain the optimum results with mininmum number of experiments by following steps shown

1. Define the process objective, or more specifically, a target value for a performance measure of the process.
2. Determine the design parameters affecting the process.The number of levels that the parameters should be varied at must be specified.
3. Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment.The selection of orthogonal arrays is based on the number of parameters and the levels of variation for each parameter, and will be expounded below.
4. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.

By applying Taguchi method the following sample were created as shown in **Table 2** and the Parameter which contributes more of analyses techinque called ANOVA

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Table 2. DoE parameters

Sample No	Input			
	Hole dia (mm)	Final dia (mm)	Feed rate (m/min)	Rotating Speed (RPM)
1	10	10.2	0.104	600
2	10	10.2	0.211	852
3	10	10.2	0.315	1260
4	10	10.4	0.104	852
5	10	10.4	0.211	1260

III. RESULTS AND DISCUSSION

3.1 Temperature Measurement

Sample No	Input				Output
	Hole dia (mm)	Final dia (mm)	Feed rate (m/min)	Rotating Speed (RPM)	Temperature (Deg C)
1	10	10.2	0.104	600	32.5
2	10	10.2	0.211	852	38
3	10	10.2	0.315	1260	36.5
4	10	10.4	0.104	852	44.5
5	10	10.4	0.211	1260	42.5

The above table is the one which specifies the temperature of the specimen when it undergoes frictional stir severe plastic deformation around the hole which is measured by the help of infrared thermometer. The temperature is expected to raise when the rotational speed is more and the taper of the tool is more. The specimen are selected depending on the methodology of Taguchi Technique otherwise 27 specimen are required to test for different taper of the tool, rotational speed (rpm) and feed rate (m/min). The temperature measurement gives the amount of energy used to work on obtaining severe plastic deformation around the hole and also the extent of Severe Plastic Deformation.

3.2 Determination of the major contribution factor

In order to determine the major process parameter that causes the maximum impact on the temperature increment around the hole while performing SPD, two approaches are employed:

- Determination of the major contribution factor by using DOE.

MiniTab software was used to create a Taguchi Design considering all the process parameters and the response which is the temperature in this case. A graph was plotted which gives the variation of feed rate, spindle speed and Delta d. the graph is shown in the following figure:

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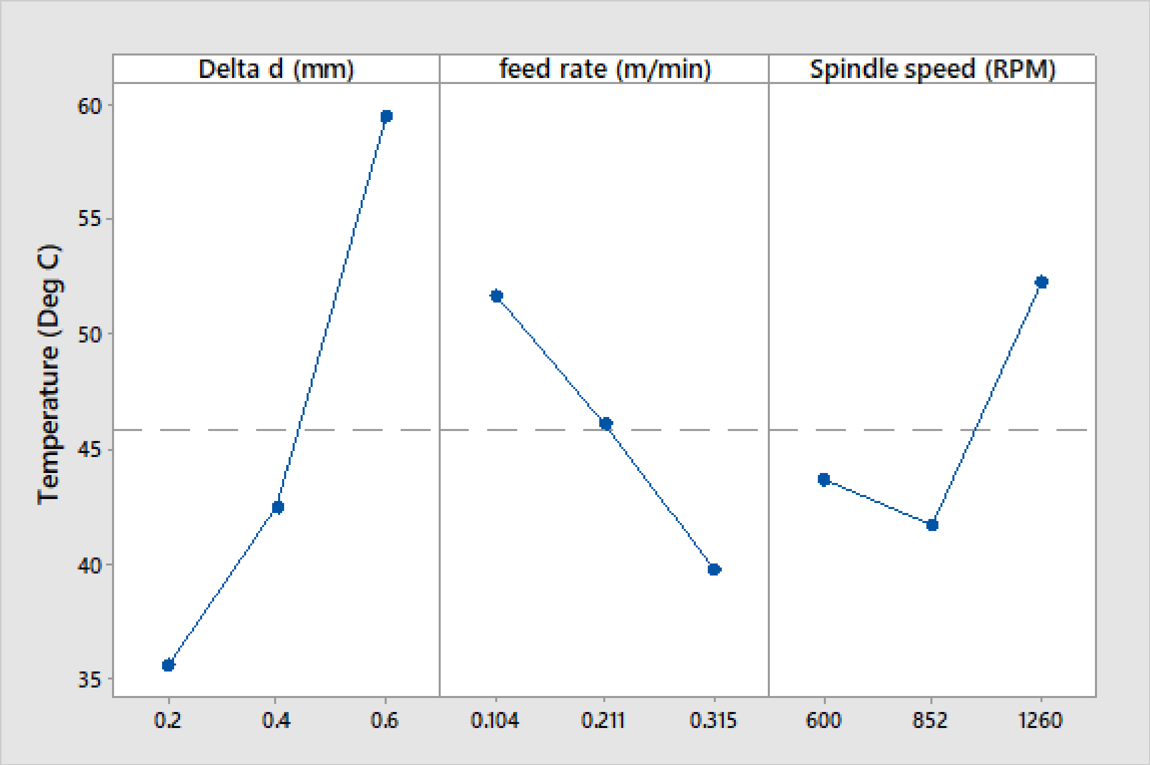

Figure 8 : Plot showing the variation of temperature with respect to different process parameters.

The above contour plot shows the variation of Temperature is more due to the parameter of Delta d, second being the feed rate and least being the spindle speed. Thus the Delta d is given rank-1, Feed rate rank-2 and Spindle Speed rank-3 which is inferred from the tool as shown below
Similarly, by using DOE analysis to determine the major contributing factor, the ranks are given to process parameters based on which parameter has the largest impact. The following Figure gives the results of the analysis done using DOE method.

Response Table for Means

Level	Delta d (mm)	feed rate (m/min)	Spindle speed (RPM)
1	35.67	51.67	43.67
2	42.50	46.17	41.67
3	59.50	39.83	52.33
Delta	23.83	11.83	10.67
Rank	1	2	3

Figure 9 : Rank of different parameters that contributes to temperature increment

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IV. CONCLUSION

The experiment was conducted to measure the roundness and parameter contributing the rise in the temperature which is the measure of degree of SPD (Lesser temperature is required).The temperature was measured by varying three parameter which are Taper, Feed Rate and Spindle speed. The following outcomes had come out.

1. The rise in the temperature is majorly due the taper of the tool which has to keep to the minimum to obtain an optimum SPD around the hole.
2. The roundness was measured for the Frictional Stir Hole Expansion process and for the mentioned parameter which was of not good quality, thus another process can be used to obtain a good quality of hole.
3. The hole quality can also be improved by slower feed rate as it take more machining time for the SPD to occur.

V. ACKNOWLEDGEMENTS

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