Microstructural Investigation of Is513cr3 by Comparing with Plain Coolant, Ice, Ln_2 Gas in Single Point Incremental Forming

M.D.Vijayakumar, G.Gopalaramasubramaniyan, V. Dhinakaran

Abstract*: Sheet metal incremental forming is an emerging manufacturing technology that allows formation of complex profiles by CNC contoured paths using a semi hemispherical tool. Single point incremental forming (SPIF) is a novel methodology of sheet metal forming operation which provides higher formability limits. This paper deals with the microstructural changes in the sheet metal which is subjected to die less forming operation. For the study of microstructure and the nature of deformation in detail, IS513Cr3 sheet is chosen as an experimental sheet metal sample. The evolution of microstructure after incremental sheet forming operation has been investigated for different samples of ice, ambient and LN2 conditions. The sheets are successfully deformed to required shape by sheet metal incremental forming operation and microstructural investigation is done by trinocular metallurgical microscope. This paper analyses the influence of material grain size that has an adverse effect on the material properties with respect to its application. The primary research scope is to fully analyze the microstructure of sheet metal influenced by various parameters and the results are compared. Further hardness is calculated in the sample with varying thickness at various locations and the results are discussed.

Index Terms*: Incremental sheet forming, CNC paths, formability limits, microstructure, trinocular metallurgical microscope, hardness.

1. INTRODUCTION

With the necessity to improve the quality of production and incorporating innovative and fail proof production techniques, there is a larger need for the development of manufacturing processes that meets global demand. Further, with the increase in the competitiveness in the manufacturing industries and products, it is necessary to improve the present scenario and adopt to latest technologies. The present topic discussed in this paper also focuses on the newer and unique manufacturing technology that is revolutionizing the sheet metal industry by reducing the cost and overall production time. The Single point incremental forming has utmost importance in the medical implants applications apart from the conventional sheet metal application. This incremental sheet forming is the feasible solution for the rapid prototyping and is a novel method of agile manufacturing that meets customer requirements. This process does not uses dedicated dies thus it reduces the overall production cost of the dies and the lead time required for the die preparation. This method requires a fixture setup to clamp the sheet metal rigidly and Computer Numerical Controller setup to generate the tool path with respect to the input program. Here the sheet is progressively bent with the feed given by the hemispherical tool. The sheet metal incremental forming has higher formability limit and hence it is widely utilized in the manufacturing of automobile sheet parts, shipyards and in the aerospace industry. This paper deals with the grain dislocations that occur in the microstructural level when the sheet metal undergoes plastic deformation under the incremental forming operation. The tests are done and results of microstructures are analyzed under various parameters like Ice, Ambient and LN2 as coolant. The hardness of the samples are measured at various locations and the feasibility of the application of these coolants are studied in detail.

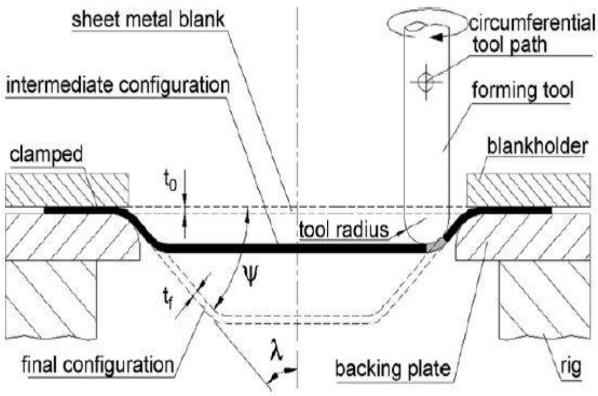

Fig.1 Incremental forming setup

2. LITERATURE REVIEW

Various researchers have investigated the feasibility of the incremental sheet forming operations. Numerous studies have been made to understand the possible failure modes during die less forming and the propagation of crack in the sheet are studied in detail. K.K.Tang [1] in his research work on fatigue crack growth has analyzed the Failure of 7075 – T6 Al Sheets. From his observations, it is found that by employing transitional functions, the effect of material, loading and geometry are incorporated and reflected in the multiscale fatigue crack growth process of 7075-T6 Al sheets. The constant change of Material, Loading Geometry in metal fatigue is necessitated by the effects of Non-equilibrium and Non-homogeneity.

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Kawai Kwok [2] also investigated the homogenization of steady state creep of porous metals in which the relationship between creep rate and porosity computed by homogenization is found to be bounded by the Hudge-Dunand model and the Hashin-Shtrikman creep model, and closely matched by the Gibson-Ashby compression and Ramakrishnan Arunachalam creep models. Nagarajan Devarajan [3] in his paper on complex incremental sheet forming using back die support has given that thinning was higher at steeper wall angle for all the alloys, from both the experimental and finite elemental analysis. It is speculated that the typical tensile nature of the loading and the associated thinning of the material at these regions caused plastic instability in the material thereby creating micro-cracks that resulted in the failure of the component. K.Isik [4] in his paper on Formability limits by fracture in Sheet metal forming has proposed the methodology that provides easy and efficient procedure to characterize formability limits by fracture in sheet metal forming. The proposed approach is found to have impact on the basis of forming limit curves (FLCs) on the onset of necking. Wenke Bao [5] in his work on Formability and microstructure of AZ31B alloy has found that the electro pulse can reduce the AZ31B dynamic recrystallization (DRX) temperature and accelerates the DRX progress, and it can also restrain the crack growth of the tested materials which in turn improves its formability. Jeswiet et al described the modifications to traditional forming methods such as conventional spinning and shear forming, forming processes in which deformation is localized [6].

III. MICROSTRUCTURAL INVESTIGATION OF ICE AND PLAIN SAMPLES

Initially for the microstructural investigation, the sample was sectioned in such a way that the cross-section of the thickness is obtained. This cross-section of the sample was prepared for the microstructure evaluations. The images of the microstructure were captured from the top surface of the incremental forming as starting point and the microstructure is captured at equal intervals. It is expected that the sample would reveal the effect of incremental forming on the microstructure and the change in the microstructure at every point is studied. Comparison of microstructure and hardness and thinning between processes carried out at room temperature, 0 degrees and Liquid nitrogen. The roughness values of ice treated and plain samples are calculated in various locations and values are tabulated as shown in the table 1.

Table1 Corresponding roughness values of ice treated and plain sample at various locations in microns

Sample Location	ICE	Plain
A	1.299, 1.289	1.068, 1.061
B	0.954, 1.004	1.062, 1.207
C	1.312, 1.794	0.976, 0.967
D	1.870, 1.556	0.961, 1.159

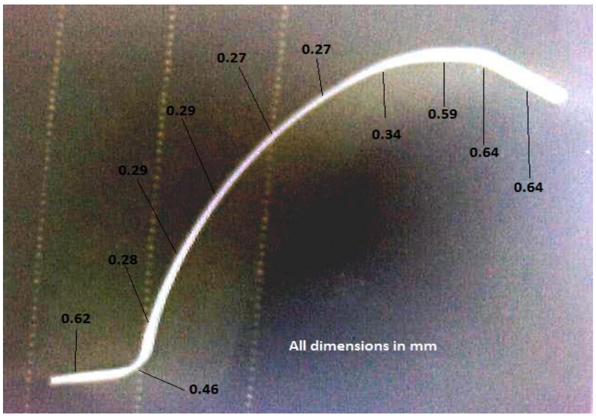

Fig.2 Ice sample used for thickness measurement

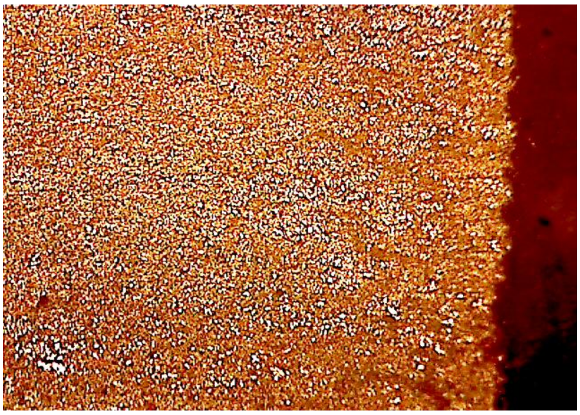

Fig.3 Microstructure of Ice sample at 150X magnification-starting point

The Incrementally formed sheet was treated with ice and thickness is measured at various locations as depicted in the figure 2.The hardness value of the ice sample is found to be 146.0 HV measured at 0.5kg load.

The figure 3 shows the microstructure of the parent metal cross-section with magnification of 150X. The microstructure shows worked grains along the direction of the rolling of the sheet. The grain orientation is along the direction of rolling. This is the microstructure at the mounting part of the process where the sheet is fixed in the machine. The Etchant used in this microstructural analysis is Nital solution.

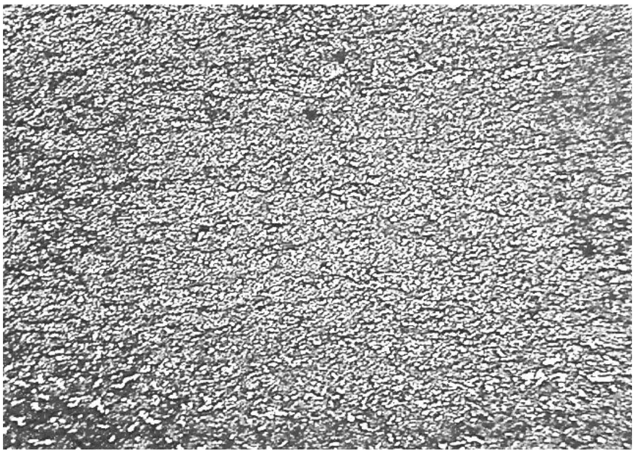

Fig.4 Microstructure of Ice sample at 150X magnification-Last point

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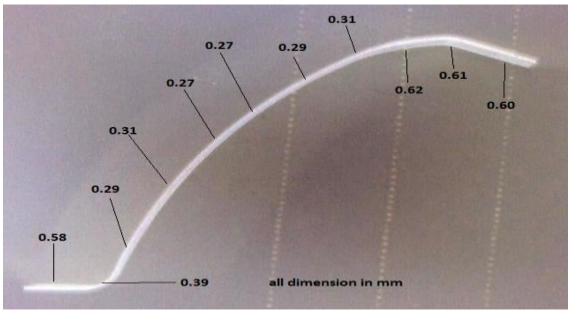

Fig.5 Plain sample used for thickness measurement

Figure 2 shows the microstructure which is the last point at the bottom of the forming geometry with grains fragmented due to compressive stress. It is observed that the grains in the bottom portion of the sample are fragmented due to the extreme compressive stress acting on the specimen by the hemispherical tool during the incremental forming operation. The thickness of plain incrementally formed sample is measured at various locations as depicted in the figure 5. The hardness value of the plain sample is found to be 97.1 HV measured at 0.5kg load.

Fig.6 Microstructure of Plain sample at 150X magnification-starting point

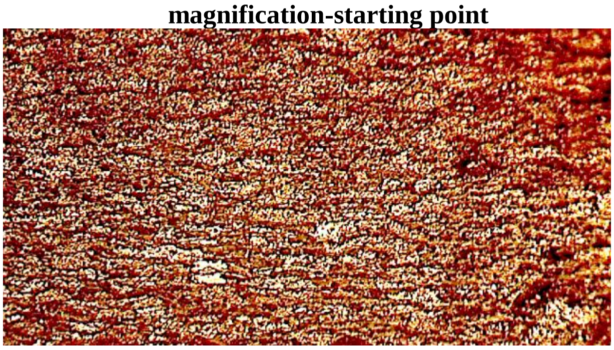

Fig.7 Microstructure of Plain sample at 150X magnification-2mm from starting point

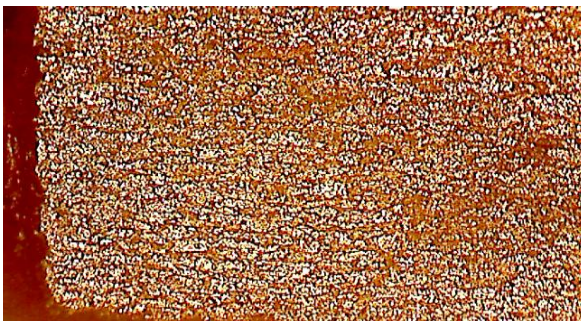

Fig.8 Microstructure of Plain sample at 150X magnification-end point

The microstructural photographs are studied at various location of the plain sample and the following inferences are observed. Figure 6 shows the microstructure of the parent metal cross-section with magnification of 150X. The microstructure shows worked grains along the direction of the rolling of the sheet. The grain orientation is along the direction of rolling. This is the microstructure at the mounting part of the process where the sheet is fixed in the machine. Figure 7 shows the microstructure of plain sample taken 2 mm away from the starting point and no change in the microstructure is observed. The microstructure shows rolled/worked grains of pearlite in ferrite matrix. Typical low carbon steel microstructure is observed. The Etchant used in this microstructural analysis is Nital solution. The figure 8 shows the last point of cross-section of the material and the microstructure of the matrix is the parent metal rolled sheet with grains of pearlite in ferrite.

IV. MICROSTRUCTURAL ANALYSIS OF SAMPLE WITH LN2

Then the microstructural analysis is done with liquid nitrogen as coolant and thickness values and hardness are measured out. Microstructure is taken at the cross-section from the top of the formed zone to the down at an interval of 3.0 mm and the microstructural images are displayed below.

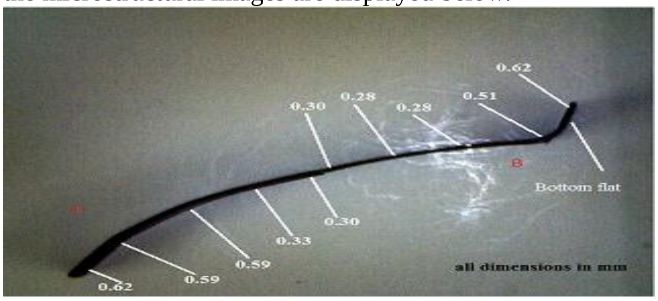

Fig.9 LN2 treated sheet metal sample

Figure.10 Microstructure of LN2 sample at 150X magnification- starting point.

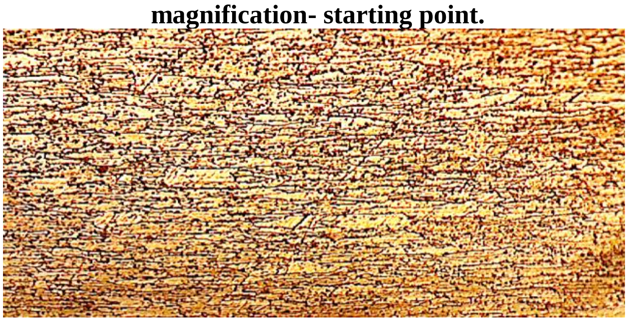

Fig.11 Microstructure of LN2 sample at 150X magnification after 3mm from formed zone from top

Figure 10 shows the un-formed zone where the incremental forming process had not started. The matrix shows the parent metal which is cold rolled low carbon steel. The microstructure shows partially elongated grains of pearlite and ferrite in ferrite matrix with magnification of 150X. . The Etchant used in this microstructural analysis is Nital solution. Figure 11 image is taken after 3 to 4 mm. from the incremental formed zone from the top. The grains have showed further strained due to cold forming incremental process. The grains of pearlite are elongated along the direction of the forming tool.

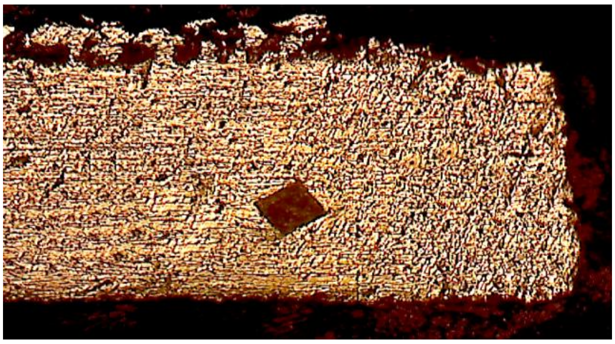

Figure.12 Microstructure of LN2 sample at 150X magnification-end point

Figure 12 shows the maximum thinning with severe banding and the grains have come closer. This zone is the center zone. Here there is maximum thinning with severe banding and the grains have come closer. Figure 13 shows the second half of the sample from the formed end to the bottom zone and it describes shows the center zone of the incremental process with maximum thinning. The microstructure shows severe banding of the ferrite and ferrite grains along the direction of the forming.

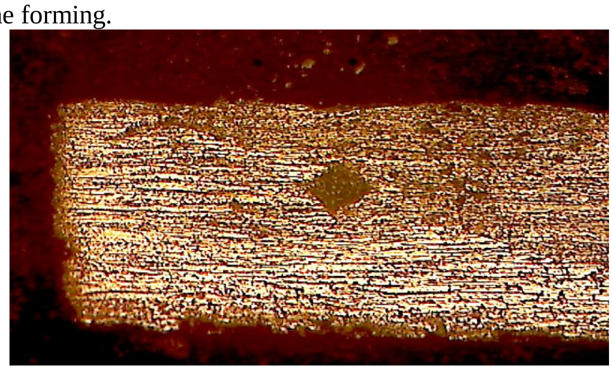

Fig. 13 Microstructure of LN2 sample at 150X magnification from formed end

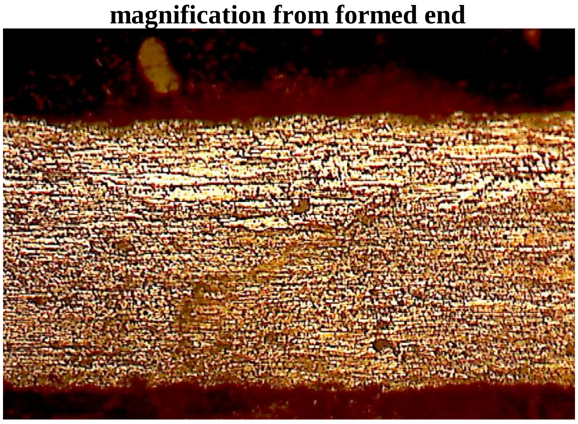

Fig. 14 Microstructure of LN2 sample at 150X magnification 3mm from formed end

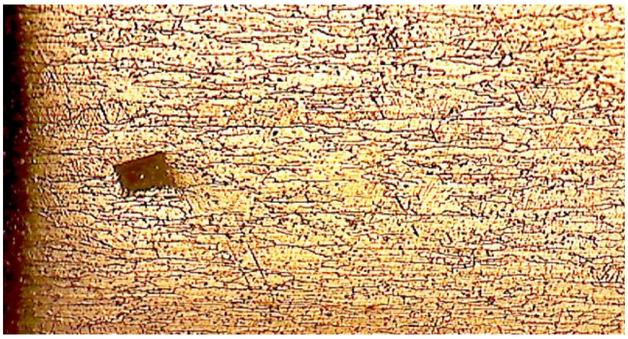

Fig.15 Microstructure of LN2 sample at 150X magnification from formed end

The figure 14 shows the next continuation of the center zone with 3.0mm of the incremental process with maximum thinning. The microstructure shows severe banding of the ferrite and ferrite grains along the direction of the forming. Figure 15 shows the parent metal cross-section with the microstructure of coarse grains of pearlite in ferrite matrix. This microstructure is comparable to the first half as shown in figure. The zone close to the parent metal at the bottom with the constituents reaching the parent metal microstructure.

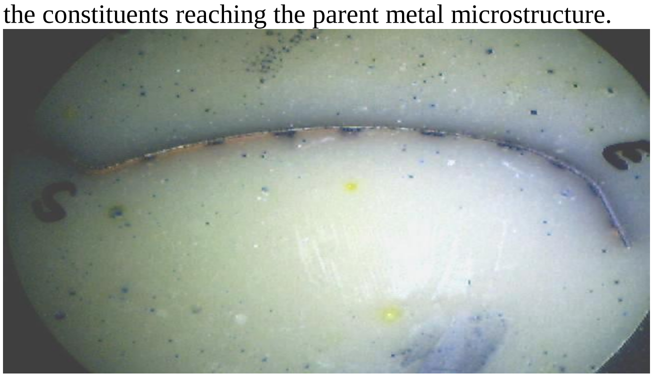

Fig.16 Plain sample

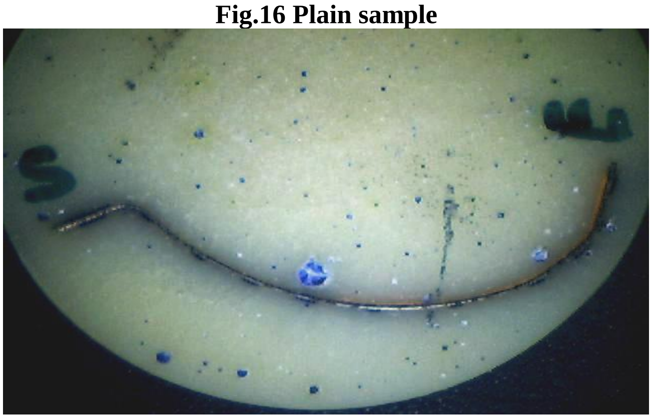

Fig.17 Ice treated sample

V. EXPERIMENTAL RESULTS

The hardness values of each samples are measured at various points in the sheet metal sample treated with ice and liquid nitrogen. The Hardness values are compared in the table 2.

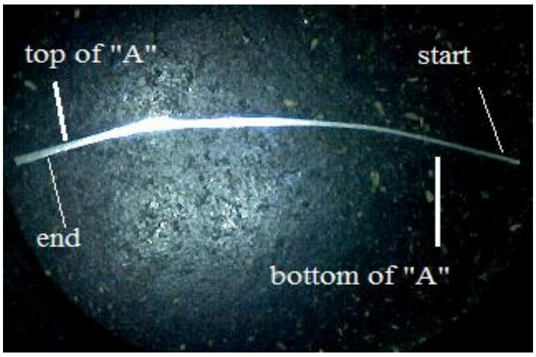

Fig.18 Top half of LN2 Treated sample

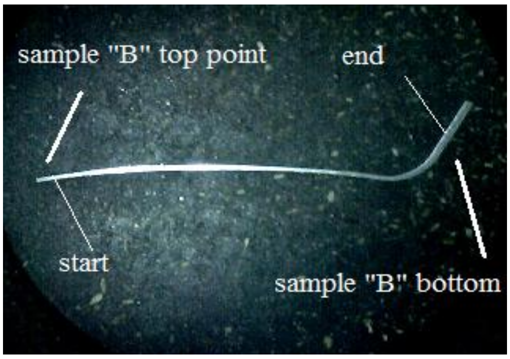

Fig.19 Second half of LN2 Sample

The figure 18 shows the top half of the incrementally formed sheet treated with Liquid nitrogen. The figure 19 shows the second half of the incrementally formed sample treated with Liquid nitrogen. The hardness values are calculated at 0.5 Kg load applied at the samples. It if observed from the hardness comparison table 2 that the hardness of plain sample and ice sample increases geometrically at various positions in the sheet. The top half and the bottom of the LN2 sample infers that the hardness initially increases and then deceases in the incremental sheet.

Table 2. Hardness comparison of samples in microns at various locations

Sl.No	Plain sample	Ice sample	Top half of LN2 sample	Bottom half of LN2 sample
1	101.6	106.4	143.0	136.6
2	102.0	103.1	147.1	132.7
3	110.1	139.8	153.6	136.0
4	139.1	144.5	152.9	139.2
5	166.2	138.7	156.6	163.3
6	167.3	163.9	155.4	168.0
7	168.2	167.0	152.6	158.1
8	168.7	169.1	112.9	165.5
9	171.1	172.1	107.8	159.8
10	172.4	175.9	108.5	163.6
11	175.1	174.6	106.6	155.3
12	178.2	173.4	105.3	156.9
13	179.5	170.9	107.8	148.3
14	174.1	165.6	105.7	146.8
15	177.0	151.9	104.9	118.2
16	164.5	142.4	106.0	113.7

V. CONCLUSION

The present research work aimed to analyze the microstructures of plain, ice and LN2 Samples of IS513Cr3 incrementally formed sheet metal. To generalize the incremental forming of sheet metal, it is necessary to optimize the lubricant used in the process. The major focus is to analyze the various failure modes of Single point incremental forming by the usage of Liquid nitrogen and the microstructural results are analyzed. The hardness of the samples are compared at 0.5 Kg load in which the results have proved comparative increase in the hardness of the sheet when treated with liquid nitrogen.

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