INVESTIGATION ON PREDICTION OF FORMING BEHAVIOUR OF BLANKS THROUGH LASER AND ULTRA VIOLET (UV) GRID MARKING METHODS DURING SINGLE POINT INCREMENTAL FORMING (SPIF) PROCESS AND ERICHSEN CUP METHOD

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Abstract: Single Point Incremental forming (SPIF) is one of the advanced forming processes developed and studied by researchers nowadays. SPIF yields in to the improved formability of the blanks and the force requirements are low as well compared to the conventional forming processes. In this research article experimental study on SPIF process is carried out on AA 6061 T6 material. A truncated cone is developed during SPIF processes using a hemispherical tool. Erichsen cup method is also adopted to form the components. In order to develop the forming limit diagram conventional grid marking technique is adopted. To develop the grid, laser marking and UV printing techniques are used and the results for both the marking processes are compared in terms of accuracy to predict the forming behaviour of material. As a result it was found that laser marking affects the forming behaviour of the blank while UV printing does not affect the material behaviour during forming process. The laser marked circles were found as the crack initiation spots which can lead to wrong prediction regarding forming behaviour of blank. UV marking yielded in better prediction of material forming behaviour.

Key words: Single Point Incremental forming, Forming Limit Diagram, Laser marking, UV marking, Erichsen Cup.

1. INTRODUCTION

There are lot of efforts have been made in order to develop the forming technology in the last decades just to come up with such a technology which yields in the better formability of the blanks. Single Point Incremental Forming (SPIF) process is one of such processes with results in to the improved formability of the blank. It is sub process of category Incremental Forming (IF) processes. In this process, deformation on the blank is provided in an incremental manner with the help of a tool which is generally spherical or hemispherical shaped. Depending upon the target shape to be formed, the tool movement is provided. Figure 1 represents the schematic of the SPIF process.

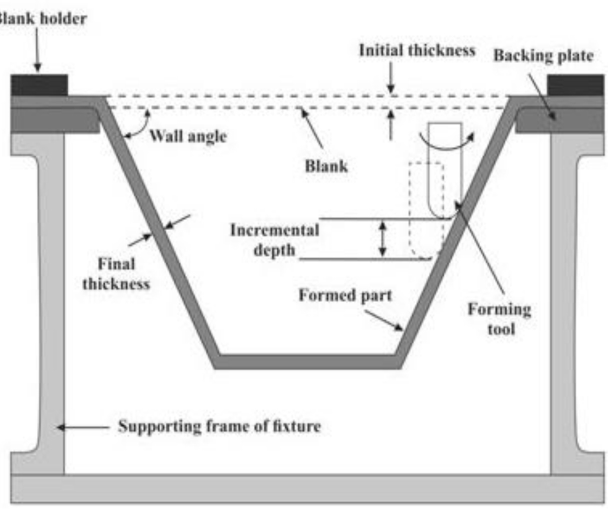


Fig. 1. Schematic representation of SPIF process

This process can be carried out on a Vertical Milling Centre (VMC) on which blank can be clamped with the help of a fixture and a backing plate is used below the blank to be formed. In this process the blank holding force is provided in such a manner that there is no chance of drawing of material during forming. During SPIF, combination of stretching and bending takes place and that leads to improve the formability of the blank (Filice et al., 2002, Centeno et al., 2014) The process parameters involved in SPIF are feed of tool, tool rotational speed, wall angle, tool path, type of tool, incremental depth, and lubrication type. There are certain limitations of SPIF process like there is restriction of thickness of blank which can be formed and it is a time consuming process (Echrif and Hrairi, 2011). In several studies tool marks (Malhotra et al., 2012) are found on the formed component which is result of inaccurate process parameter selection. The responses which are studied by the researchers after the SPIF process are like thinning of blank (Gulati et al. 2016), surface roughness (McAnulty et al., 2017), geometrical errors (Gupta and Jeswiet, 2019, Desai et al. 2017) and force requirements (Kumar et al. 2019). In order to study the formability of the blanks, Forming

Limit Diagram (FLD) (Gatea et al., 2016) is also developed. In order to develop the FLD, major and minor strain developed during the forming process is required to be measured. These measurements can lead to develop the FLD for a forming process for a particular material and operating conditions. There are many advanced methodology available to measure these strains like Digital Image Correlation (DIC) (Pan et al., 2018). But the disadvantage of DIC system is that it is very costly. There is another method called as grid marking method (Shrivastava and Tandon, 2019) which can be helpful in measuring the strains developed during the forming processes. In this method, grid of circle or square is printed on the blank before forming process as per the ASTM E2218-15. After the forming process is completed the deformation of grid is measured and from that major and minor strains are determined and FLD is developed. The challenge in this case is that, the applied grid on the material should not fade away after or during the forming process. This particular problem is more in case of materials like aluminium and its alloys.
In this research article, two different grid marking technique namely laser marking and UV printing are compared in terms of accuracy and feasibility in predicting the forming behaviour of AA 6061 T6 material during the SPIF process.

2. EXPERIMENTAL WORK

2.1 SPIF process

For the present experimental study, AA 6061 T6 having thicknesses 0.5, 1.0 and 1.6mm is used. In order to compare the two grid marking methodology, the forming experimentation was performed on the NC milling machine (Make: M/s. Batliboi, Surat) as indicated in Figure 2. The fixture, to hold the blank, was fabricated from mild steel material and it was designed so that it can hold the blank of 100x100mm^2 dimensions.

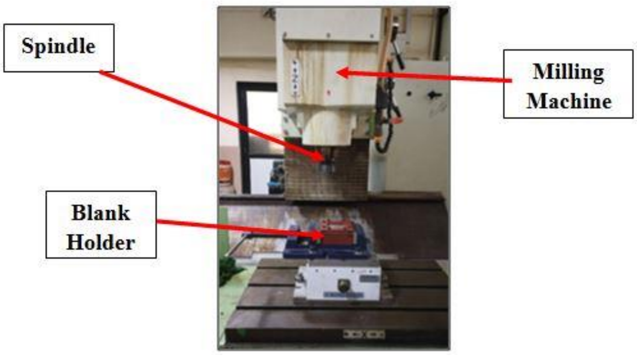


Fig. 2. NC milling machine used as Single Point Incremental forming setup

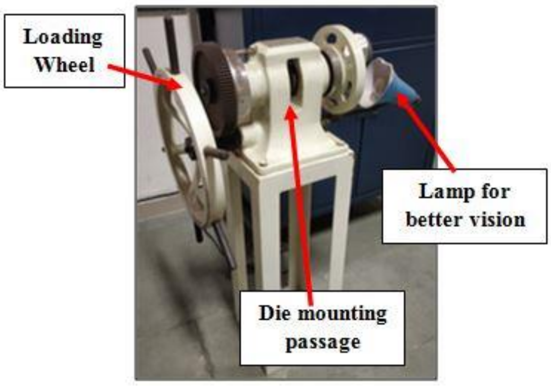
For SPIF process, a hemispherical tool having 2.27mm of radius was developed from the H13 material (Ghamdi and Hussain, 2015). During the experimentation tool radius compensation was not considered and tool was not given any rotation. During forming, outward to inward radial tool movement was considered which was provided with the help of a part program. Some of the experimental parameters are represented in the Table 1.

Table 1. Constant SPIF process parameters

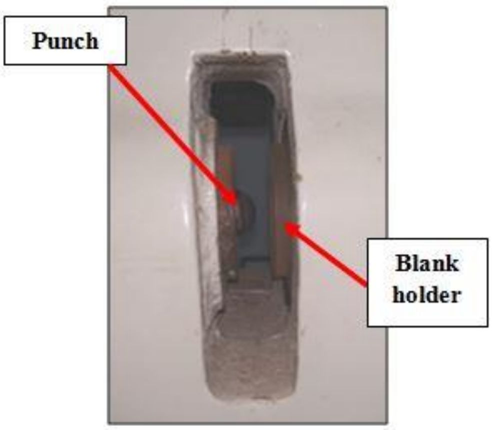
Sr. No.	Parameter	Unit	Magnitude
1	Tool Feed	mm/min	1000
2	Wall angle	Degree	45
3	Incremental depth	mm	0.25
4	Truncated cone height	mm	15
5	Top diameter of truncated cone	mm	50

2.2 Erichsen Cup Test

In addition to the SPIF process, one more standard forming method, Erichsen cup test, was adopted to form the blanks. The Erichsen setup adopted was developed by M/s. Ratnakar Enterprise, Ichalkaranji and its RET-20 model was used for the experimental purpose (see Figure 3). The mentioned model was capable of testing blank dimension of 90x90 mm^2 and 70x90mm^2. So, all the blanks were cut in to the mentioned size and the forming process was completed manually.



(a)



(b)

Fig. 3. Erichsen cup test method setup: a) Erichsen cup setup; b) Magnified view of die mounting passage

2.3 Grid Marking Techniques

In the present experimental study, two methods namely laser marking and UV printing were adopted to develop the grid on the blank so that after forming process, the deformed grid can be measured and FLD can be developed.

In order to achieve adequate contrast for laser marking, a layer of black paint of thickness 18 to 20μm was applied on the blank before laser marking. After that laser marking was done as per the ASTM E2218-15 standard. UV printing was applied on the blank before forming using the same ASTM standard. The grid marking process was followed by the Erichsen and SPIF processes.

After the forming process, major and minor strain measurement was done for SPIF formed components. In order to investigate the thinning of the blank, thickness measurement was done using ultrasonic thickness gauge.

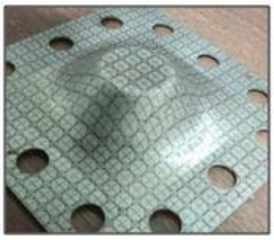
3. RESULTS

After forming of the blank with the help of Erichsen cupping process and SPIF, responses such as thickness, forming height, surface finish and failure locations in the formed components were investigated.

3.1 Formed Component

The UV marked components formed after Erichsen test and SPIF process are represented in Figures 4(a) and (b) respectively. It can be clearly observed that the circles of high strain areas were deformed and were transformed in to ellipse. The measurement of deformed circles was done for both the marking methods for SPIF formed components.

(a)

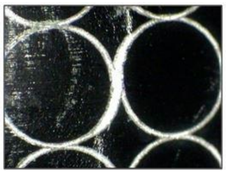


(b)

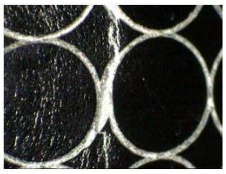
Fig. 4. Formed component after forming process: a) Erichsen cup (Failed); b) SPIF Cup (Successfully formed)

3.2 Failure Locations

After forming process, initial observations were made regarding the failure locations. For Erichsen test, failure locations for all the blanks for laser and UV marking are represented in Figures 4 and 5 respectively. In Erichsen test, for laser markings blanks, it was observed that the failure was initiated from the marked circle only. For all the blanks, the crack was initiated from the circumference of laser marked circle as indicated in Figure 5. For UV marked samples, the failure initiation locations were different for different samples (Figure 6).



(a)



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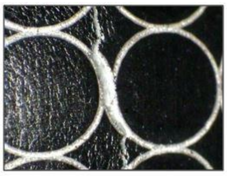
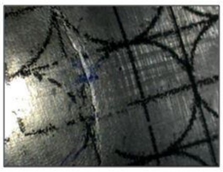


(c)

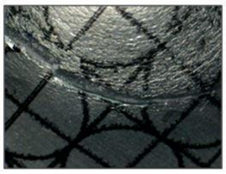
Fig. 5. Failure Locations for laser marking during Erichsen test method: a) 0.5 mm thick blank; b) 1.0 mm thick blank; c) 1.6 mm thick blank

During laser marking, the grid of circle is printed on the blank by removing small amount of material from the blank and that will lead to develop the stress concentration due to the discontinuity of thickness in the material of blank. That is the reason that all the failures are from circumference of laser marked circle. On the other hand, in UV marking, no material removal action takes place during the grid marking process. So, UV marking leads to predict the actual behaviour of the blank during the forming process while laser marking involves failure due to marking which doesn't allow the prediction the actual behaviour of blanks.



(a)

(b)



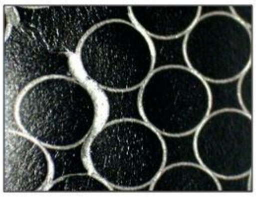
(c)

Fig. 6. Failure Locations for UV marking during Erichsen test method: a) 0.5mm thick blank; b) 1.0mm thick blank; c) 1.6mm thick blank

Similar results were observed for the SPIF formed components. Figure 7 represents the failure locations in laser marked blank which was formed using SPIF process. It can be clearly observed that the failure was initiated from the circumference of circle.

(a)

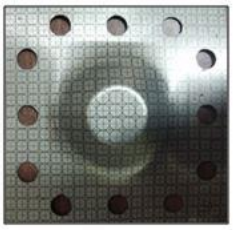
(b)



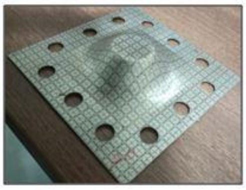
(c)

Fig. 7. Failure Locations for laser marking during SPIF process: a) 0.5mm thick blank; b) 1.0mm thick blank; c) 1.6mm thick blank

Figure 8 depicts the UV marked component which was successfully formed in truncated cone. Forming height of 1mm was successfully achieved for UV marked component without any kind of failures.



(a)



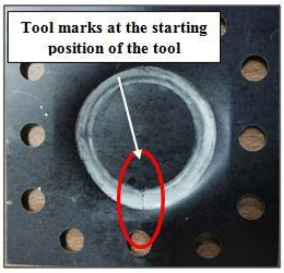
(b)

Fig. 8. Formed components for UV marking during SPIF process: a) 0.5 mm thick blank; b) 1.0 mm thick blank

The experimental conditions for laser and UV marked samples were kept same although UV marked resulted in better forming of blanks and laser marking resulted in failures of blanks during the SPIF process. This indicates that laser marking results in to the early failure of the blank due to which the actual forming behaviour of blank cannot be predicted.

3.3 Tool marking and Surface finish

Surface finish is one of the major aspects of the SPIF process. If the SPIF process parameters are not properly controlled, SPIF may yield in to the poor surface finish and tool markings can be observed in the formed components. Figure 8 indicates the tool markings observed for the laser marked sample and Figure 9 represents the tool making observations for UV marked samples.

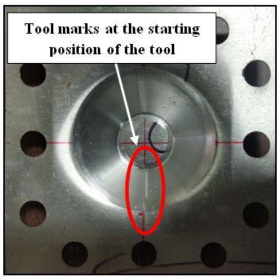


(a)

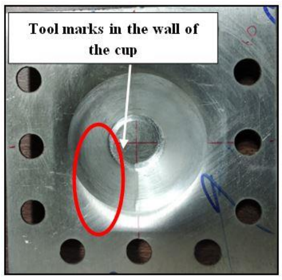
(b)

Fig. 9. Tool markings for laser marked blanks in SPIF process: a) 0.5mm thick blank; b) 1.6mm thick blank

Tool markings are observed at two different locations in the formed components. One location where tool markings are observed is at the starting position of the tool from where the tool initiates the forming process (Figures 9(a) and 10(a)). The second location is the wall sections of the cup where the tool makings are observed (Figures 9(b) and 10(b)). The tool marking is result of higher magnitude of incremental depth. As the tool incremental depth will decrease the tool marking will disappear and the surface finish can be improved. But on the other hand the time to form a single component will increase. So, considering the forming time proper magnitude of incremental depth should be adopted.



(a)



(b)

Fig. 10. Tool markings for UV marked blanks in SPIF process: a) 0.5 mm thick blank; b) 1.0 mm thick blank

Surface finish in the formed components was measured at different four locations as represented in Figure 11. The starting position of tool was considered as number 1 and from there in clockwise direction the roughness measurement was done on the locations as indicated in Figure 11.

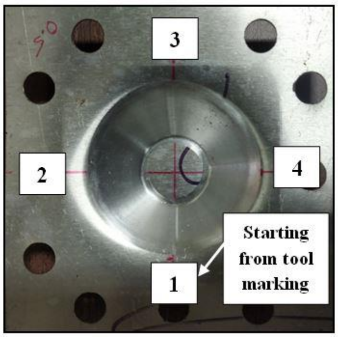


Fig. 11. Location number for surface roughness measurement

For UV marking, the magnitude of surface roughness at different locations was measured and represented in Figure 12. It can be observed that the magnitude of surface roughness at location 1 and 3 is high compared to location 2 and 4. Location 1 is the spot where the tool deforms the blank in incremental manner and due to this interaction of tool and blank surface finish is not good at this spot. At location 3, the half path of the entire tool movement completes and tool stays there for fraction of second during SPIF process. This may lead to generate the waviness in the surface which may result in bad finish of surface.

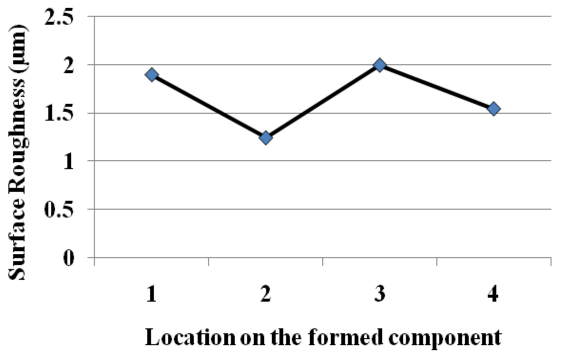


Fig. 12. Surface roughness at different location for UV marked SPIF formed component

The comparison of average surface roughness of all four locations in SPIF formed component for laser and UV marking is shown in Figure 13. The initial observation indicates that there was not much different in the surface roughness for both the marking methods. It is also observed that as the blank thickness increases the surface roughness increases irrespective of marking method adopted. As the thickness of the blank increases, high amount of force is required to deform the blank which may have damage the top surface of the blank which might have resulted in the high surface roughness.

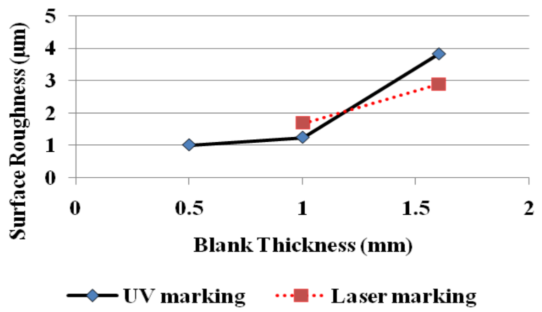


Fig. 13. Comparison of average surface roughness in SPIF formed component for UV and Laser marking

3.4 Forming Height

For all the formed components, forming height comparison was made for Erichsen and SPIF process. Figure 14 indicates the cup height comparison for Erichsen cup test for laser and UV marked samples. It can be observed that for all the blank thickness, the forming height achieved in UV marked samples was more in comparison to the height achieved for laser marked samples. Figure 15 represents the forming height comparison between both the marking methods for the SPIF process. The forming height achieved by the UV marked samples was high in comparison to the height achieved by the laser marled samples.

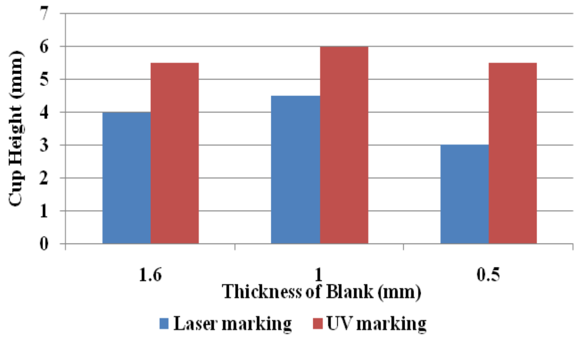


Fig. 14. Forming height comparison for Erichsen cup test for laser and UV marking

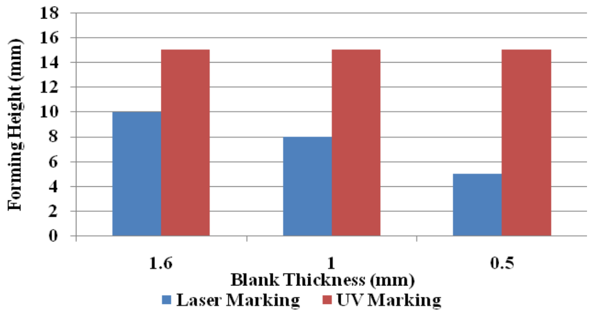


Fig. 15. Forming height comparison for SPIF for laser and UV marking

3.5 Thickness measurement

After forming process was completed, thickness measurement was carried out at various locations in the formed component for Erichsen and SPIF process. Figure 16 represents the minimum thickness observed in the formed cup for Erichsen test for laser and UV marking.

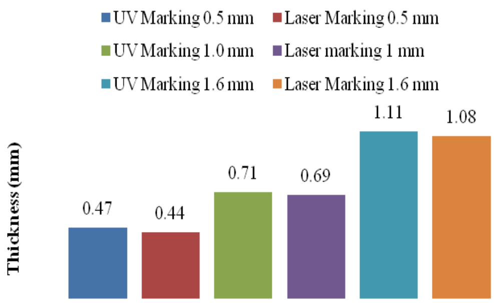
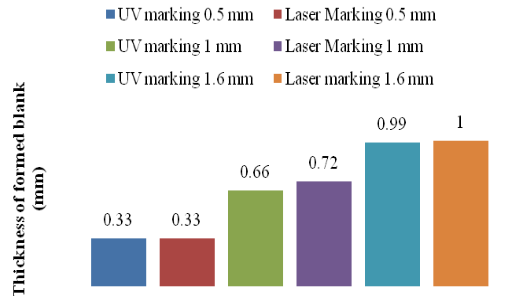
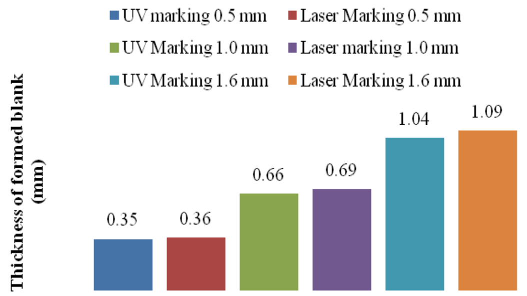


Fig. 16. Minimum thickness in the formed component for Erichsen cup test

From Figure 16 it can be observed that the minimum thickness for UV marking is more comparison to the minimum thickness observed for laser marking. As represented in Figure 14, the forming height observed for UV marking was more in comparison to the height achieved for laser marking. Despite of yielding in more forming height, the thickness in the UV marked blanks was high compared to the laser marking. This indicates that UV marking does not affect the forming behaviour of the blanks. On the other hand, for laser marked samples, more thickness reduction is observed for low forming height which indicates that forming behaviour of the blank is affected by the laser marking method.



(a)



(b)

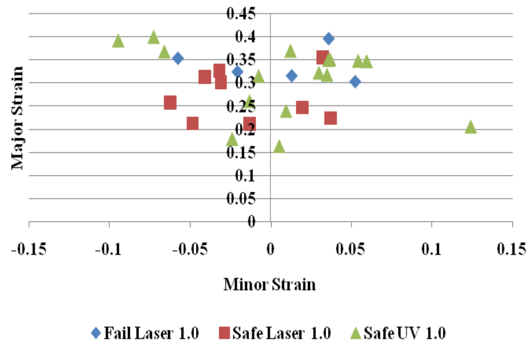
Fig. 17. Minimum thickness measurement in SPIF formed component: a) in wall; b) at corners

In the SPIF formed components, thickness measurement was done at two different locations namely at corners and in the wall of the formed components. The comparison of thickness measurement between UV and laser marking in wall and at corners of the formed component is shown in Figures 17(a) and (b) respectively.

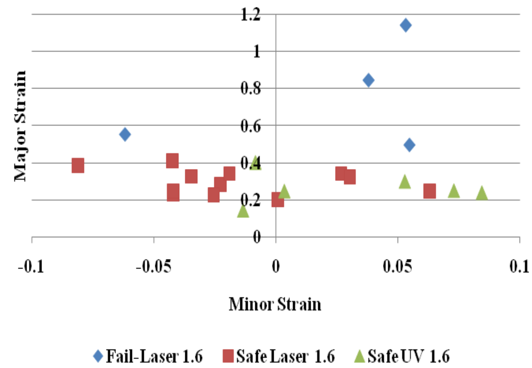
From Figure 17 it can be noted that the minimum thickness observed for the UV marking was less by a small margin from the minimum thickness in laser marked samples. For UV marked samples, there was no failure observed and successful forming up to 15mm of forming height was observed. On the other side, forming height for laser marked samples was very low in comparison to the laser marked samples. So, as the forming height increases, the thinning in the blank increases and that leads to decrease the final thickness in the formed component. Due to this phenomenon the thickness observed for laser marking is high comparison to the height observed in UV marking components. This also indicates that not only the good forming height is achieved but also the forming behaviour of the blank is not affected due to UV marking.

3.6 Forming Limit Diagram (FLD)

The formability of laser and UV marked blanks was investigated by developing forming limit diagram for SPIF. After completion of forming process, deformed grid was measured on Vision Inspection System. Measurement at different critical points of the formed component was done. For SPIF process, FLD for both the marking process adopted is indicated in Figure 18. For 1.0mm thick blank the comparison of major and minor strain is represented in Figure 18(a). The formability of UV marked sample is found to be better in comparison to the formability of the laser marked sample. The laser marked samples failed due to marking that resulted in the low formability of the blanks. For 1.6mm thick blank, there was not much difference in the formability observed as represented in Figure 18 (b).



(a)



(b)

Fig. 18. Forming Limit Diagram for SPIF process: a) for 1.0 mm thick blank; b) for 1.6 mm thick blank

4. CONCLUSIONS

In this article experimental work regarding prediction of forming behaviour of blanks is represented. Two grid marking methods namely laser marking and UV printing method were adopted and responses like thinning, surface roughness, strain measurement and forming height measurement were studied. Following points can be stated as the concluding remarks.

The laser marked samples failed from the marking only which indicates that the laser grid affected the formability of the blank. UV marked sample failed in random fashion during Erichsen cup method. This indicates that UV marking can yield in actual prediction of formability of the blanks.

As the thickness of blank increases the surface roughness in the formed component increases. A high magnitude of surface roughness was observed at the starting position of tool and at the location where tool takes a pause during incremental forming process.

UV marked samples showed better forming height for both the forming methods while laser marked sample failed quite early.

Despite of being formed for more forming height, UV marked resulted in less thinning while laser marked samples showed significant thinning for small forming heights.

UV marking method predicted higher formability of the blanks in comparison to the laser marking method.

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