Limit dome height test of very thin brass sheet considering the scaling effect

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Abstract. The effect of reduction of material geometry in metal forming process is important and is more effective when material size less than 100 micron. Thin brass sheet of 30, 50, 90 micron thickness were tested by in-plane uniaxial and out-of-plane limit dome height (LDH) test to investigate the size effect. The test was carried for both as-received and annealed specimen. The microstructure of all tests was determined in details by electron back scattered diffraction (EBSD) microscopy technique. There was a clear dependency of mechanical behaviour observed on part miniaturized of both tensile and LDH test. The limiting strain is obtained maximum at plane strain path in LDH test having more misorientation. The 50 micron sheet in biaxial strain path required more load and have larger major strain, more texture and Taylor factor value.

1. Introduction

The study of part miniaturization effect is necessary for an optimized production process, because the mechanical properties of thin sheet metal are mostly different from bulk material. This lead to size effect in micro scale material geometry compared to macro scale [1, 2]. The size effect was studied by tensile testing of copper, nickel, aluminium etc. by several researcher and observed that the yield stress decreases with scaling down the material geometry [3-4]. The researchers were investigated the scaling effect on deep drawing and low formability, punch load, thickness distribution was observed [5]. The grain size versus thickness observed by Kals et al. that shows an important role in forming process [6, 7]. The effect of miniaturization and microstructural parameters like grain size, misorientation, twin fraction, Taylor factor, texture index are more in material having dimension less than 100 μm. The Taylor factor was studied by many researcher, i.e higher Taylor factor have more dislocation density and larger intragranular misorientation [8-11]. There are less studies done on the effect of microstructural parameters in case of thin sheet. In the current research work miniaturization and microstructure effect were studied by uniaxial tensile as well as limit dome height (LDH) test as tensile test does not give sufficient information about different state of stress and strain.

2. Tensile test of very thin brass sheet

A conventional tensile test machine Instron 3345 single vertical column type tensile test machine of capacity 5KN was used for tensile testing with a strain rate of 10^{-4}. The tensile curve for working material 30, 50, 90 μm thickness brass is shown in figure 1. The tensile test for each condition was carried out for three times for repeatability of result. The elongation is more in 90 μm thin sheet followed by 50 and 30 μm thin sheet. On the other hand the flow stress is more in 30 μm thin sheet

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followed by 50 and 90 µm thin sheet. This is lead to the miniaturization or scaling effect. The microstructure study was carried out for better understanding of the different deformation property for different thickness of specimen by FEI Quanta TM 200 Hv electron back scattered diffraction (EBSD) microscopy and analysed by TSL OIM Analysis 7.2 software. The EBSD sample was prepared by mechanical polishing followed by diamond polishing and electro polishing (electrolyte of 20% orthophosphoric acid and 80% water). The EBSD microstructure image of as received brass material of different specimen thickness is shown in figure 2 (a-c). It is observed that, the grain size in 30 µm sheet is very small even not indexed by EBSD. Which may be the cause of high flow stress and less elongation in 30 µm sheet. Brass sheet of 50 and 90 µm have 7 and 9 µm respectively, which shows comparatively less flow stress and more elongation. Due to very less elongation the material was not suitable for any for further deformation work. Therefore, the received material was annealed with 650º C for 20 minute to modify the microstructure and used for formability study by LDH test.

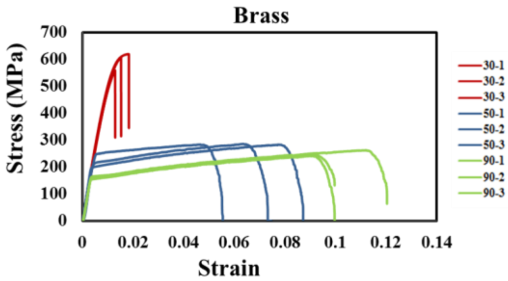

Figure 1. Tensile test of as received brass material with different specimen thickness.

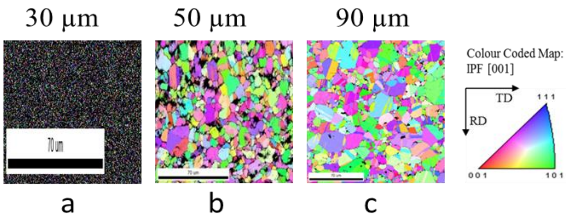

Figure 2. EBSD image (microstructure) of as received brass material of different specimen thickness.

3. Limit dome height (LDH) test of very thin brass sheet

The state of stress and strain used in sheet metal forming process are not only uniaxial condition but multiaxial conditions. Therefore, the tensile data is not sufficient to describe the forming limit and detail material behaviour in sheet metal forming process. LDH is the out-of-plane deformation method and performed in different strain path like uniaxial, plane strain and biaxial. The same machine Instron 3345 with a LDH attachment as shown in figure 3 (a) was used for LDH test. The sample dimension for biaxial, plane strain and uniaxial are scaled down and optimized shown in figure 3 (b-d) respectively. The LDH samples for different strain path were prepared by wire electric discharge machine (EDM) machine and printed with dot pattern for strain measurement. Half hemispherical punch of diameter 15mm were used for LDH test with 10^{-3} rate of punch displacement. The punch stroke versus load graph are shown in figure 4-6 for 90, 50, 30 µm thickness respectively. It is observed that the maximum load requirement decreases with miniaturization and from biaxial to uniaxial.

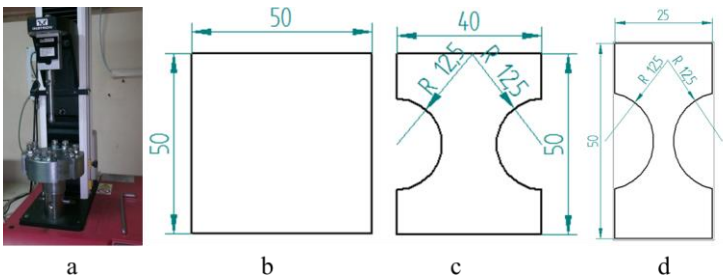

Figure 3. a) Experimental setup, b-d) Sample dimension for different strain path**.**

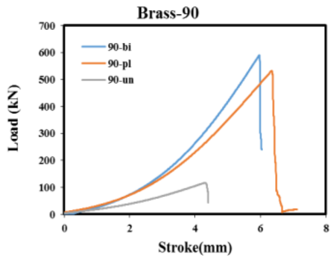

Figure 4. Punch stroke versus load plot for 90 µm thickness brass material.

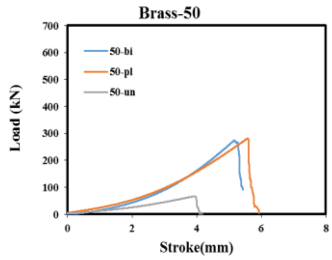

Figure 5. Punch stroke versus load plot for 50 µm thickness brass material.

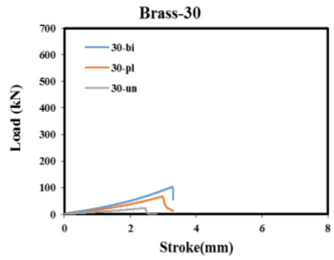

Figure 6. Punch stroke versus load plot for 30 µm thickness brass material.

The strain was measured in stereo microscope by measuring the minor and major axis before and after deformation for three strain path. The respective strain is calculated by the ratio of difference of final and initial dimension to initial dimension. The forming limit diagram (between major and minor strain) is shown in figure 7. It is observed that the maximum limiting strain is found at plane strain condition for different specimen thickness. A clear scaling/size effect is observed, that the formability (Limiting strain) decreases with decreasing thickness from 90 to 30 µm. Microstructure study was carried out to investigate the detailed deformation behaviour. Grain size was quantified in figure 8 from the TSL analysis of EBSD image shown figure 13. It is observed that the grain size decreases in uniaxial strain path but increases from uniaxial strain to biaxial strain path irrespective of thickness. The misorientation development shown in figure 9 is more on plane strain path due to the higher limiting strain in plane strain condition figure 7. Twin decay (figure 10) is more in higher thickness with deformation in all strain path but in 30 µm less decay in uniaxial and more in plane strain and biaxial. Taylor factor value is highest in 50 µm biaxial condition as shown in figure 11, so the load requirement is also more in 50 µm biaxial strain path shown in figure 5. The texture decreases with deformation (figure 12), except increasing in 50 µm biaxial strain path condition, which may be the cause of higher major strain in FLD of at 50 µm biaxial strain path (figure 7).

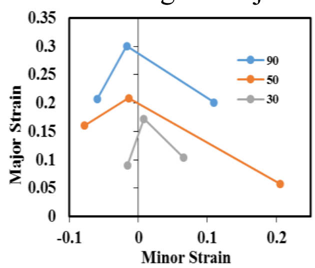

Figure 7. Forming limit diagram of brass material with different specimen thickness.

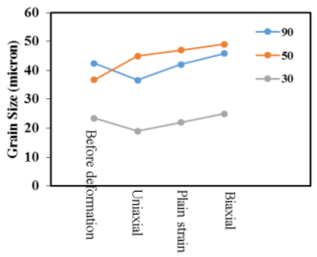

Figure 8. Grain size of different strain path with different specimen thickness.

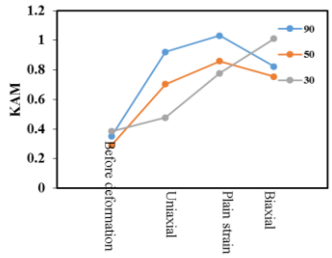

Figure 9. Kernel average misorientation development of different condition.

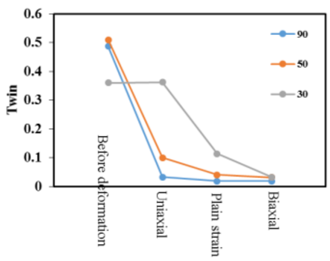

Figure 10. Twin decay of brass in different strain path with different specimen thickness.

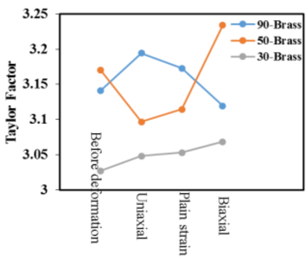

Figure 11. Taylor factor of brass in different strain path with different specimen thickness.

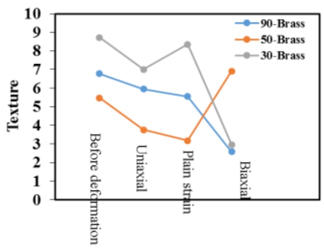

Figure 12. Texture index of brass in different strain path with different specimen thickness.

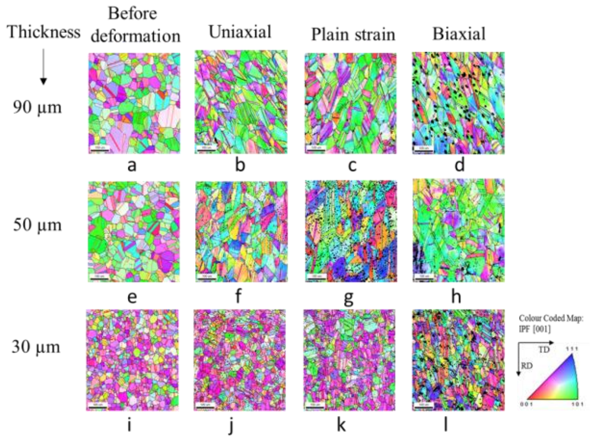

Figure 13. Tensile test of as received brass material with different specimen thickness.

4. Conclusions

Thin brass sheet of 30, 50, 90 µm thickness and comparable microstructure were tested in in-plane tensile and out-of-plane LDH test. The elongation of as-received material were found very less. Microstructure were modified by annealing for better formability. The size effect was observed in both testing that the mechanical property decreases with scaling the geometry. The limiting strain is obtained maximum at plane strain condition in LDH test for different thickness having more misorientation. The 50 micron sheet in biaxial strain path required more load and have larger major strain, more texture and Taylor factor values.

5. References

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