

Analysis of Formability of face-centered-cubic Structured Aluminum Alloy and Hexagonal Closed Packed Commercially Pure Titanium

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Abstract: The continuous demand for light weight and cost reductions, in the aerospace industry lead to development of different metal forming techniques with higher formability. In this study the deforming behaviour of face-centered-cubic Structured Aluminum Alloy and Hexagonal Closed Packed Commercially Pure Titanium under different lubrication condition is analyzed. Due to different types of bonding among atoms in face-centered-cubic Structure and Hexagonal Closed Packed structure exists, this leads to differences in capability of forming to a required shape. As the light weight components are desired for aircrafts, the maximum formability is desirable to achieve a uniform thickness of formed component without reduction of thickness. Generally, formability depends upon forming conditions, crystal structure as well as on coefficient of hardening at room temperature. The parameters which influence the formability are analyzed and optimized. It is evaluated that high temperature deforming improves formability for both materials. It is also evaluated that the tribological conditions varied due presence of lubricant, Hence influence the forming behaviour and formability.

Key words : Formability, Crystal structure, coefficient of hardness, Lubricant

1. Introduction

Aluminum alloys are developed with many outstanding attributes that resulted to a wide range of applications. Aluminum is having lightweight and good corrosion and oxidation resistance capabilities. These alloys have the face-centered cubic, FCC structure. This is stable up to its melting point. The FCC structure contains multiple slip planes, this crystalline structure greatly contributes to the excellent deformation behaviour for forming. Whereas, Commercially Pure CP Titanium is also have excellent corrosion resistant, having less specific weight and high/moderate temperature working capabilities. The



CP titanium industry has Hexagonal closed packed structure, HCP having less slip planes. This leads to meager formability. Aluminum and titanium alloy are the most abundant metal available in the Earth's crust. As a result of aluminum, FCC crystalline structure with relatively low rates of work hardening, production of aluminum alloys components is possible at room temperature. The number of dislocations in the matrix dramatically increases in cold working this act as barriers to slip. This results increase in strength in cold worked components. Aluminum is having great importance in day to day use such as for beverage cans, foil, food processing and cooking utensils, electrical, architectural and transportation applications. Aluminum alloy is finding its great applications in aero industry, on other hand Titanium and its alloys are work horse for aerospace industry. Its ability to withstand moderately high temperatures without creeping, titanium alloys are used in aircraft, spacecraft and missile production. Generally for these applications, titanium is alloyed with aluminum, zirconium, nickel [1] and vanadium. Thus titanium alloys are most suitable for critical components such as exhaust ducts for helicopters, Air inlet system and Hydraulic system[2]. Two thirds of total titanium metal produced is being used in aircraft engines and frames, specially titanium alloy Ti6Al4V accounts for almost 50% of all alloys used in aircraft applications [3]. Due to its high specific strength and excellent corrosion resistant properties its uses increased manifold, leading to development of many plastic deformation theory and practical methods. The analysis of the electronic structure, type of chemical bonds [4], Pugh's criterion [5] and elastic constants such as the Poisson ratio may help in estimating ductility but physics of plastic deformation cannot be represented well. The adoption of the generalized stacking fault energy surface, γ surface, facilitated rapid development of the dislocation properties [6–9], and Peierls-Nabarro model, P-N model [10-11], by concluding that γ surface can be useful in estimating Peierls stress. Rice and Thomson [12] explained about onset of ductile behavior, which takes place if spontaneous emission of dislocation is feasible at the crack tip. He also showed Energy barrier for dislocation nucleation [13] is unstable stacking fault energy. Tadmor and Hai [14], suggested that critical stresses are required to Generate twinning, trailing, and leading partial dislocations. These can be explained using unstable stacking fault energy, stacking fault energy surface minimum at path for partial dislocation, and stacking fault energy surface, maximum for twinning partial dislocation. Waghmare, U. Waghmare, E. Kaxiras, and M. Duesbery, [15], told that unstable stacking fault energy is fundamental for all the existing current models. Thus plastic deformation models establish that motion of dislocations and nucleation is possible for certain directions and planes these are called slip systems. The Peierls-Nabarro model [16-17] generally gives group of active slip system which are useful for determination of critical stress required to move rigid dislocation. Mostly, slip modes in crystal Lattices are described [18] with the knowledge of plastic formation based on Peierls relation. Generally for hexagonal structured, Alpha commercially pure titanium, CP Ti, there are four types of slip system on three glide planes [19] and fifth one is twinning. These all modes are sensitive to dopants which can influence individual system [20-21]. All systems are to be considered for formability prediction. Thus formability studies on titanium and its alloy is a success road map for developing indigenous aerospace industry. Formability is the ease with which a sheet metal could be formed into the required shape without undergoing localized necking or thinning or fracture. Formability is a term applicable to sheet metal forming. Sheet metal operations such as deep drawing, cup drawing, bending etc., involve extensive tensile deformation. Therefore, the problems of localized deformation called necking and fracture due to thinning down are common in many sheet forming operations. It depends upon intrinsic material properties and also depends upon extrinsic conditions prevailing during forming. These can be strain rate, thickness of sheet metal, blank size and shape and

lubricant used during forming. The lubricant also plays vital role in forming operation. Particular lubricant is suitable for particular forming operation. Thus these optimized process parameter yields production and enhance formability.

In present study different parameters such as blank size, material thickness and lubricants Graphite grease, grease yellow MT and PTFE is selected. Taguchi design of experiment is used. Analysis of mean and analysis of variance is done for different values of Erichsen index obtained from different conditions of formability test. The formability tests are carried out under similar conditions for both material CP titanium and aluminum alloy 6061.

2. Present Work

In present work materials selected are commercially pure titanium alloy, CP titanium and aluminum alloy 6061-T6. Material composition of CP titanium and aluminum alloy 6061- T6 is mentioned in Table 1. CP titanium and aluminum alloy 6061 of different sheet metal thickness as given in Taguchi design of experiment is taken and the formability test carried out at room temperature using different lubricant. The Erichsen cupping test was carried out using a hydraulic press and die fabricated according to BIS-IS 10175 standard and shown in Fig.1. The result obtained from Erichsen cupping test, carried out according to Taguchi Design of Experiment were analyzed, compared and evaluated with different parameters taken in to consideration. The parameters Blank size, B S, Blank thickness, B T and Lubricant are taken in to consideration. Blank sizes are circular 90 mm diameter, and Circular, cut diagonally opposite with 30 mm diameter semi-circle Circular, cut diagonally opposite with 20 mm diameter semi-circle, and lubricants are graphite grease, grease yellow MT and PTFE. The blank thickness are 0.5, 0.7, and 0.9 mm. The Taguchi design of experiment is carried out and accordingly L9 array is selected which is shown in table No 2.

Table 1 Chemical composition of as received materials

Material selected	N	C	H	O	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
CP Titanium	0.05	0.08	0.015	0.40								Balance	
Aluminum 6061-T6					0.59	0.45	0.28	0.028	1.015	0.27	0.04	0.05	Balance



Fig.1. Formability test using hydraulic press and die fabricated as per to BIS-IS 10175 standard

Table 2 Taguchi design of Experiment (L9 array)

Blank size	Blank thickness	Lubricants
1	1	1
1	2	2
1	3	3
2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

3. Result and discussion

The Erichsen cupping test is carried out for different sizes of samples. The motion of the punch was stopped just at the initiation of crack. . The Erichsen index value is obtained from the test by measuring the cup height. Each test was repeated thrice and average value of the Erichsen cup is taken in to consideration. The Erichsen index value was evaluated under different lubricating condition, different sizes and shape sample with grease yellow MT, PTFE and Graphite grease. The samples before formability test and after the test are shown in Fig.2 and 3.

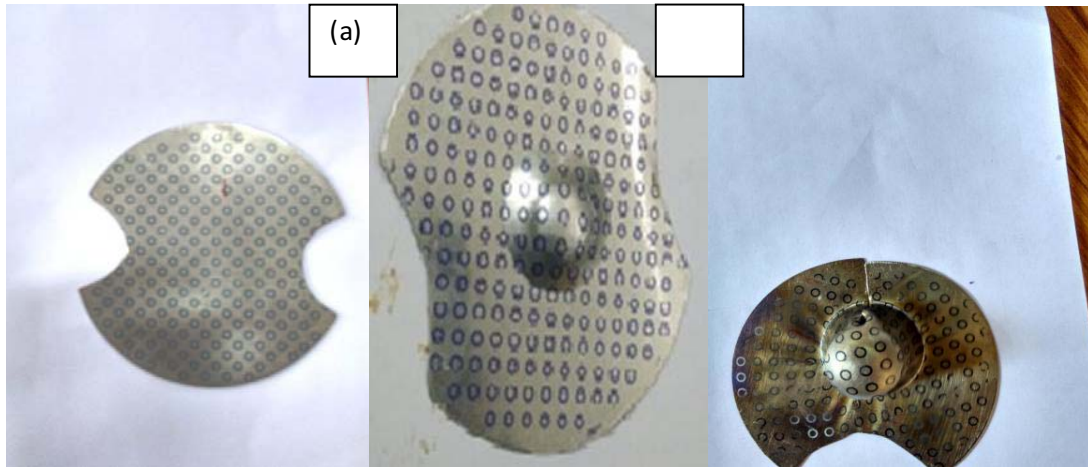


Fig 2 Sample before formability test Fig.3 Samples after formability test (a) Aluminum 6061- T6 (b) CP titanium

Analysis of mean and ANOVA analysis is carried out taking Erichsen index value obtained experimentally. Bigger is better quality criteria is selected. The analysis of mean values are presented in Fig. 4. The Fig.4 shows that highest value for blank size (Circular, cut diagonally opposite with 30 mm diameter semi-circle), highest value for blank thickness, 0.9 mm and graphite grease as lubricant. This can be attributed to, as blank is cut diagonally opposite, there is least resistance by the material for deformation. At the same time some wrinkle can be seen on the tested specimen (Fig 3 b). This shows that material is having least resistance while moving in to die. This also suggest for optimized value of blank holding force is necessary. The more thickness of the material has shown better formability than other specimens. This can be attributed to sufficient volume of material is available for drawing into cup. It is also observed that samples of aluminum and CP titanium deformed well without any fracture, as required lubrication between punch and blank was available. The maximum contribution was from lubricant graphite grease. The percentage contribution of each factor is also calculated using Qualitek 4 software. The results obtained are presented in **Fig.5**.

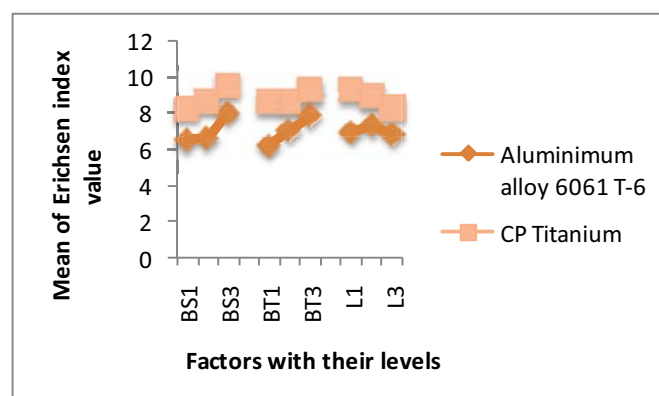


Figure 4 Main effects of parameters (Blank size, BS, blank thickness, BT, lubricant, L

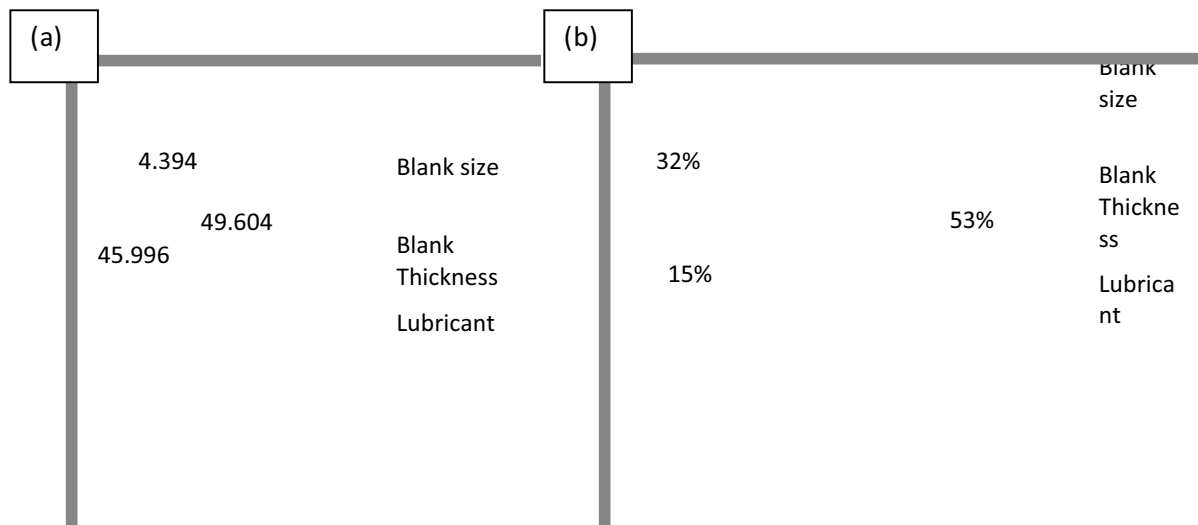


Fig. 5 Percentage contribution of each factor based on ANOVA analysis using Qualitek 4 software, (a) aluminum alloy 6061, (b) CP titanium

Fig. 5 shows that maximum contributing factor is blank size and next is blank thickness. The influence of lubricant on the formability of material is less in comparison to blank thickness and blank shape in case of aluminum alloy 6061- T6 where as in case of C P titanium maximum contributing factor is blank size and next is lubricant. Contribution of Blank thickness on the formability of CP titanium is lesser than other factor.

4. Conclusion

The Erichsen cupping test is carried out for different sizes of samples. The Erichsen index value was evaluated under different lubricating condition, for different sizes and shape sample with grease yellow MT, PTFE and Graphite grease. The following conclusions are drawn.

The higher thickness of materials both C P titanium and aluminum alloy 6061 have better formability.

The optimized parameters for aluminum alloy 6061 are blank size of Circular.

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