Experimental Analysis of Formability of Commercially Pure Titanium under PTFE Lubricated Conditions

To cite this article: Anoop Kumar 2018 IOP Conf. Ser.: Mater. Sci. Eng. 455 012052

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Experimental Analysis of Formability of Commercially Pure Titanium under PTFE Lubricated Conditions

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Abstract: It is essential to know the correct thickness to which a product can be developed with adequate strength and ductility. In this study the Influence of sheet thickness on formability of material Commercially Pure Titanium under Polytetra Floro Ethylene (PTFE) lubrication condition is experimentally investigated according to BIS-IS 10175 standard using Erichsen Cupping Test. Generally formability of a material depends on intrinsic material properties and prevailing process parameters. The process parameters such as lubricating conditions which alter tribological conditions during forming are taken into considerations. The process parameters are analyzed by selecting different thickness specimens of commercial pure titanium alloy. It is evaluated that the formability of the material commercially pure titanium alloy varies on thickness variation. It is also evaluated that formability of materials selected in the study differs under different lubricating conditions.

Key words: Formability, Thickness, tribological conditions, Erichsen cupping Test

1. Introduction

To increase the competitiveness of the Indigenous aero engine industry in world market alternative manufacturing methods for civil and defence aero engine structures are desired, in order to reduce product cost, enabling weight reduction and thereby reducing fuel consumption. Traditionally, these structures mainly consist of large-scaled single castings of e.g. titanium- and nickel based super alloys. By fabrication, some components are instead built from sheet metal parts. The components built from titanium alloy sheet metal for engine structures and for fuselage needs to be produced with new developed high temperature methodology with better formability in order to achieve reduced competitive production cost and better productivity. The manufacturing technology for titanium is generally at high temperature and high temperature forming leads to different product defects. The titanium is ninth most abundant element in the earth's crust and the seventh-most abundant metal. It finds its application in heat exchangers aerospace industry due to its high specific strength [1,2], high corrosion resistance [3,4], crack resistance [5] and excellent mechanical properties [6] at elevated temperatures. This is due to the
excellent combination of properties such as elevated strength to weight ratio, high toughness, and good fatigue properties which make them attractive for many industrial applications [7]. 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 [8] and vanadium. Thus titanium alloys are most suitable for critical components such as exhaust ducts for helicopters, Air inlet system and Hydraulic system[9]. 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 [10]. The titanium alloy Ti6Al4V is alpha-beta alloy and on other hand the alpha titanium alloys are having better strength and better creep resistance properties at moderate high temperatures but not formable in ordinary conditions. 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. Generally thinning of sheet metal is not advisable in forming operation and different thickness material is subjected to different capacity of forming. Thus it is necessary that different forming limit curves should be used for different thicknesses to get the most accurate results [11]. The many experimental studies [12, 13] and theoretical [14] studies related to effect of sheet thickness on formability are being carried out on steel, still experimental studies on CP titanium are required to be strengthen. Anisotropy also is a major concern in sheet metal operations. When a sheet metal is subjected to plane strain deformation, the critical strain, namely, the strain at which localized necking or plastic instability occurs can be proved to be equal to 2n, where n is the strain hardening exponent. For uniaxial tensile loading of a circular rod, the critical or necking strain is given to be equal to n. Therefore, if the values of n are larger, the necking strain is larger, indicating that necking is delayed. In some materials diffuse necking could also happen. Simple uniaxial tensile test is of limited use when we deal with formability of sheet metals. This is due to the biaxial or tri-axial nature of stress acting on the sheet metal during forming operations. Therefore, specific formability tests have been developed, appropriate for sheet metals. Loading paths could also change during sheet metal forming. This may be due to tool geometry or metallographic texture.

In the present study Erichsen cupping test is used. The process parameters are analyzed by selecting different thickness specimens of commercial pure Titanium alloy. It is evaluated that the formability of the material commercially pure titanium alloy varies on thickness variation. It is also evaluated that formability of materials selected in the study differs under different lubricating conditions.

2. Present Work

The material selected in the study is CP titanium and microstructure of as received material is given in Fig.1. Mechanical properties of as received Material and material composition is mentioned in Table1 and 2. Design of Experiment (DOE) is carried out as per Taguchi Method and presented in Table 3. Formability test is carried out at room temperature using PTFE as lubricant. The Erichsen cupping test
is carried out using a hydraulic press and die fabricated according to BIS-IS 10175 standard as shown in Fig 2. Different blank shape and sizes used for formability test are shown in Fig 3.

The result obtained from Erichsen cupping test, carried out according to Taguchi Design of Experiment were analyzed, compared and evaluated with different parameters taken into consideration. The parameters and their levels are shown in Table 4. Different blank shape and sizes are shown in Fig 3.

Table 1 Mechanical Properties of as received CP titanium

| 0.2% Proof Stress (MPa) | Ultimate Tensile Strength (Mpa) | Percentage Elongation |
|------------------------|-------------------------------|-----------------------|
| 677                    | 775                           | 23                    |

Table 2 Chemical composition of as received CP titanium

| N | C | H | O | Ti |
|---|---|---|---|----|
| 0.05 | 0.08 | 0.015 | 0.40 | balance |

Table 3 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          |

Table 4 Taguchi Design of Experiment, factors and their levels

| Factors                    | Level 1                    | Level 2                                      | Level 3                                      |
|----------------------------|----------------------------|----------------------------------------------|----------------------------------------------|
| Blank shape and size       | Circular 90 mm diameter    | Circular, cut diagonally opposite with 20 mm diameter semi-circle | Circular, cut diagonally opposite with 30 mm diameter semi-circle |
Table 5 Taguchi Design of Experiment, factors and their levels

| Factors                  | Level 1                                    | Level 2                                                                 | Level 3                                                                 |
|--------------------------|--------------------------------------------|-------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Blank shape and size     | Circular 90 mm diameter                   | Circular, cut diagonally opposite with 20 mm diameter semi-circle      | Circular, cut diagonally opposite with 30 mm diameter semi-circle      |
| Blank Thickness          | 0.5 mm                                     | 0.7 mm                                                                  | 0.9 mm                                                                  |
| Lubricant                | Graphite grease                            | Grease Yellow MT                                                        | PTFE                                                                    |
3. Result and discussion

The Erichsen cupping test is carried out for different samples as given in Fig 4. The motion of the punch was stopped just at the initiation of crack. The PTFE is used as lubricant in between punch and sheet metal. The Erichsen index value obtained from the formability test is taken to study influence of other parameters and also to compare other lubricant with PTFE. Each test was repeated thrice and average value of the Erichsen cup is taken into consideration. Fig. 5 represent Erichsen index value for different samples varying in blank sizes, sample 1: circular with 90 mm diameter, sample 2, material is cut diagonally opposite 10 mm radius semi-circle, sample 3, material is cut diagonally opposite 15 mm radius semi-circle, with PTFE lubricated condition. It is evident from the Fig. that formability of the CP titanium is more for sample 3. It can be attributed to as material is cut diagonally opposite, so reduced volume condition of material offered less resistance to deform. Furthermore, the Erichsen index value was compared for CP titanium under different lubricating condition with PTFE lubricated condition. The different sizes and shape sample were tested with grease yellow MT, PTFE and Graphite grease as per Taguchi design of experiment.

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. 6. The Fig. shows that highest value for third level of blank size, highest value for blank thickness, level 3 and lubricant graphite grease. The more thickness of the material has shown better formability than other specimens in study. The similar results were obtained by JD Bressan [15]. The percentage contribution of each factor is also calculated using Qualitek 4 software. The results obtained are presented in Fig. 7.

Fig. 4 a and b before formability test, c after formability test
It is evident from Fig. 7 that blank size has contributed more than lubricant and least contribution is obtained from blank thickness.

4. Conclusion

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

The blank size affects the formability of material selected in the study.
The blank size has contributed more than lubricant and blank thickness and least contribution is obtained from blank thickness.

Thicker sheet metal of CP titanium shows better formability than thin sheets of CP titanium.

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