

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

Anoop Kumar

St. Martin's Engineering College Dhullapally, Secunderabad -500100, T.S. (India)

* Author E. Mail: anoopkumar.anoopkumar@yahoo.com

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 Fluoro 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 strengthened. 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 Fig2. 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 in to consideration. The parameters and their levels are shown in Table4. 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	B alance

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	Level2	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	0.7mm	0.9mm
Lubricant	Graphite grease	Grease Yellow MT	PTFE

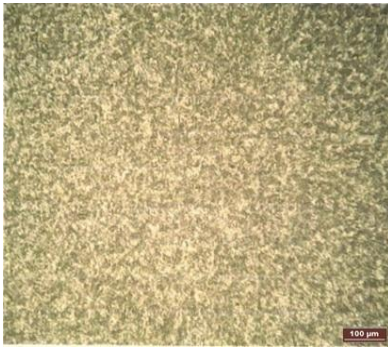


Fig. 1 Initial microstructure of CP titanium



Fig 2 Formability test set up using hydraulic press and die.

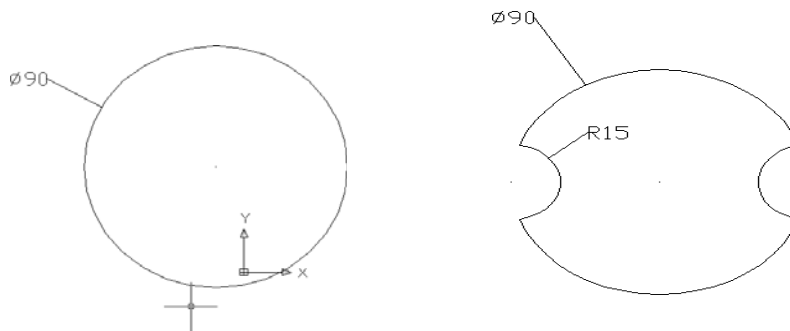


Fig. 3 Different sizes of Blank

Table 5 Taguchi Design of Experiment, factors and their levels

Factors	Level 1	Level2	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	0.7mm	0.9mm
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 in to consideration. Fig. 5 represent Erichsen index value for different samples varying in blank sizes, sample1 :circular with 90 mm diameter, sample 2 , material is cut diagonally opposite 10mm 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 3and 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.

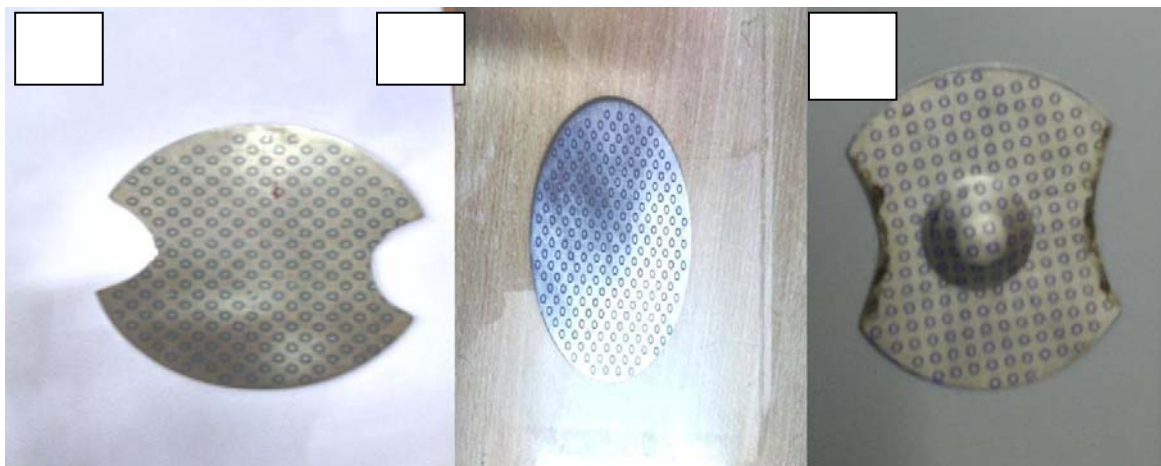


Fig.4 a and b before formability test, c after formability test

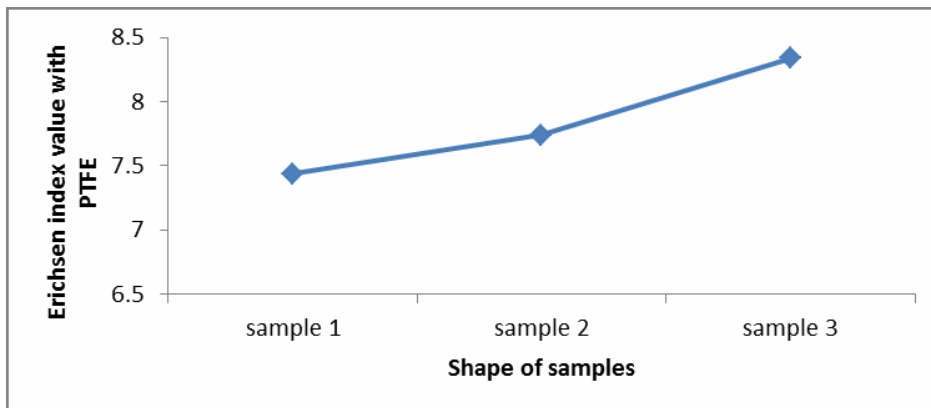


Fig. 5 Erichsen index value for different samples with PTFE lubricated condition

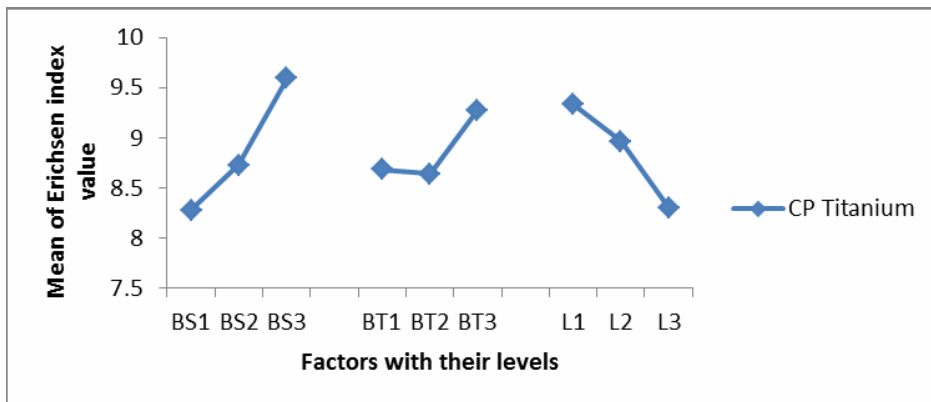


Fig. 6 Main effects of parameters (Blank size, BS, blank thickness, BT, lubricant, L)

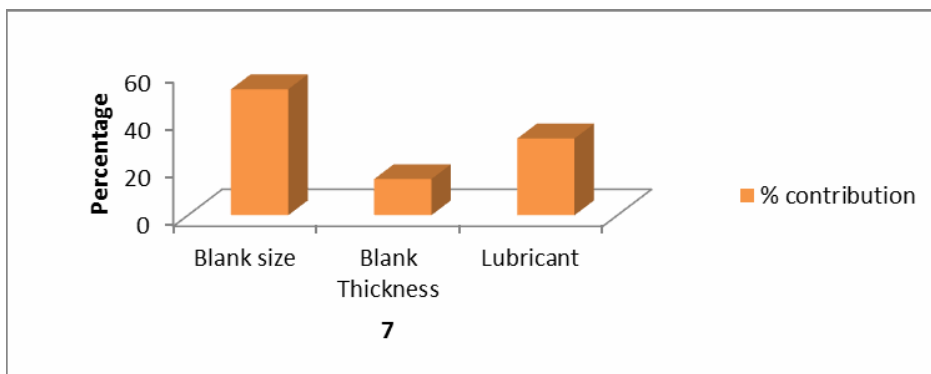


Fig. 7 Percentage contribution on of parameters.

It is evident from Fig.7 that blank size has contributed more than lubricant and least contribution is obtained from blankthickness.

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 condition, 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.

References

- [1] Young-suk IM, Bong-Hyun EE, Seung-Han YANG, Prediction of forming limit curve for pure titanium sheet, Transaction of Non ferrous metals society of China, Volume 28 , issue 2, Feb 2018, page 319-327.
- [2.] N.G. Tupper, J.K. Elbaum and E.M. Burte, "Opportunities of Cost-Affordable Titanium Aerospace Structures," J. Metals, 30 (1978), pp. 7-13.
- [3] L. Morawenkasaki, C. Jansinski, A. Concanda, Determination of Formability Limits for Grade 1 Titanium Sheet by means of ALSAD Method, Procedia Engineering, 207, 2017, pp 548-553.
- [4] J.R. Myers, R.B. Bomberger and F.R. Froes, "Corrosion Behavior and Use of Titanium and Its Alloys in Aerospace and Commercial Environments," J. Metals, October 1984, Volume 36, Issue 10, pp 50–60.
- [5] Moiseyev, Valentin N. (2006). Titanium Alloys: Russian Aircraft and Aerospace Applications. Taylor and Francis, LLC. p. 196. ISBN 978-08493-3273-9.
- [6] Antonio Fiorentino, Elisabetta Ceritti, Claudio Giardini. Experimental and Numerical method for analysis of warm Titanium Sheet stamping out of an automotive component, Advance in Material Science and Engineering, Volume 2015, Article ID 137964, pages 10.
- [7] V. Balasubramanian, V. Jayabalan and M. Balasubramanian, Effect of current pulsing on tensile properties of titanium alloy, Journal of Material & Design, vol. 29, 2008, pp. 1459–1466.
- [8] Andrew E. Kramer (5 July 2013). Titanium fills vital role Boeing and Russia. *The New York Times*, July 2013.
- [9] Gang Liue, Young WU, Jie Zhao, Kai Wang, Shijian Yuan, Formability Determination of Titanium Alloy Tube for High Pressure Pneumatic Forming at Elevated Temperature, Procedia Engineering 81, 2014, pp. 2243-2248.
- [10] Fen- Quiang Li, Jian-Hua Mo, Jian –Jun Li, Liang Huang, Hai- Yang Zhou, Formability of Ti6Al4V Titanium Alloy Sheet in Magnetic Pulse Bulging, Materials and Design, , 52, 2013, PP337-344.
- [11] Kleemola HJ, Kumpulainen JO Factors influencing the forming limit diagram: part II—influence of sheet thickness. J Mech Work Technol 3(3–4), 1980, 303–311.
- [12] Narayanasamy R, Narayanan SC, Experimental analysis and evaluation of forming limit diagram for interstitial free steels. Mater Des 28, 2007, 1490–1512.
- [13] Kumar DR , Formability analysis of extra deep drawing steel. J Mater Process Technol, 2002, 130–131:31–41.
- [14] Kim Y, Kim C, Lee S, Won S, Hwang S, Forming limits for anisotropic sheet metals. JSME Int J Ser A 46(4), 2003, 627–634.
- [15] JD Bressan Influence of thickness size in sheet metal DOI 10.1007/S12289-008-0030-3 Springer paris 2008.