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Formability Studies on Titanium Grade 2 Sheet using Erichsen Cupping Test

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ABSTRACT

Titanium grade 2 (Ti-Gr2) sheet is widely preferred in industrial applications for its better corrosion resistance, formability and weldability. Formability of Ti-Gr2 sheet in room temperature is challenging and various factors are considered to improve the formability of the sheet. In this research work, formability behavior of the Ti-Gr2 sheet is investigated at room temperature. Erichsen cupping number (cup height) was determined to understand the formability of Ti-Gr2 sheet in Erichsen Cupping machine MET-20 model. In this work, priorly the finite element simulation was carried out using finite element software to predict the fracture zone. Experimentation was performed consecutively to identify the Erichsen cupping number in dry and wet conditions for 0.5,1.0 and 1.5 mm sheet. The critical area identified as weak zone in finite element software matches with the fracture zones found in experimentation. It has been identified that lubrication using SL320 synthetic oil has increased the Erichsen Cupping Number of Ti-Gr2 sheet.

Keywords Titanium Grade 2 sheet, FEA simulation and Erichsen Cupping Test.

I. INTRODUCTION

Formability is the extent to which a sheet metal can withstand the plastic deformation without defects. In the formability test, the sheet undergoes tearing at a particular location as a result of necking. Sheet metal forming process like bending, curling, expanding, hammering and seaming, hydroforming is carried out in industries based on the product requirements. The Ti-Gr2 sheet is formed into several complex shapes and profiles in industry. In this work, the formability behaviour of Ti-Gr2 sheet metal is studied under room temperature. The commercially pure titanium grade sheets are difficult to form under room temperature conditions.

The cupping test consists of pressurizing a punch against sheet metal which results in deep penetration followed by crack propagation and crack formation at a particular location in the sheet. The crack formed on the sheet in the cupping test is studied based on the parameters considered in the experiment. FEA simulation was carried out to predict and understand the weak zone in the sheet. Erichsen number is determined at different sheet thickness in the cupping test of Ti-Gr-2 sheet. The journals are identified based on the relevant field of the study and analyzed to understand the experimental and theoretical procedure followed in the work. Monika Singh et al [1] explored the formability of aluminum alloy using Erichsen cupping test method. The Erichsen number was identified in properly annealed and chemical composition tested specimen. The results showed that forming thin sheets is difficult and Erichsen number is greater at the high temperature and decreases with the increase in hardness. Lin Prakash P S et al [2] analyzed the cupping height of Tailor Welded Blank (TWB) using electron beam welding process. Titanium (Grade-2 & Grade-5) sheets are welded together by electron beam welding. Erichsen cupping number of TWB was close to Grade 5 sheet and minimum compared to Grade 2 sheet. The premature failure without necking was observed at the weld zone of TWB in the Erichsen cupping test. Dmytro Lumelskyj et al [3] compared both the experimental and numerical simulation of strain localization detection in Nakazima formability test for DC04 grade (Carbon steel Material). The limit strains have been calculated numerically and experimentally for specimens undergoing deformation at different strain paths. Ding-kai Liu et al [4] investigated the influence of different rolling routes on mechanical anisotropy and formability of commercially pure titanium sheet. Erichsen test indicated Cross Rolling (CR) has higher Erichsen value depicts better stretch formability when compared to Unidirectional Rolling (UR). The deep drawn cups of UR show earing whereas the CR shows the nearly uniform height with avoid of earing. G. Yoganjaneyulu et al [5] investigated the fracture behavior of titanium grade 2 sheets by using the single point incremental forming process. The influence of fracture behavior is based on tool diameter and spindle speed. The forming limit diagram reveals the change of the limiting major strain values with change in speed and vertical depth. It is identified that void size, void ratio, ligament thickness and void area fraction increases with increase in spindle speed. Yasunori Harada et al [6] studied the formability of pure titanium sheet in square cup deep drawing through multi stage deep drawing. The square cups were drawn by various stages by placing the blank parallel & 45°. It is observed that the sheets were drawn successfully without any cracks at the 2nd stage but due to deformation resistance or ironing the cracks were observed at the corners in the 3rd stage process. The drawn cup is heated at intermediate stage and it is coated with oxide layer at the same stage by reheating and this coated cup is successfully drawn without any cracks due to oxide layer coating. L.Morawinski et [7] determined the formability limits for titanium grade-1 sheet by means of ALSAD method. The results obtained by means of the ALSAD method shows good formability of the GR1 titanium sheet were verified by the 3D digital microscope and compared with the results obtained by means of the strain rate (t-d) method. The ALSAD method has been especially useful to find relatively small differences in strains between the occurrences of different types of defects. Julita Winowiecka et al [8] performed the evaluation of drawability of tailor welded banks made of titanium alloys grade-2 and grade-5. Numerical simulation based on PAM-STAMP 2G and experiment results was to determine the plastic deformation occurring in the material during stamping process. Increase in holding down force causes a growth in plastic strain & decrease in sheet thickness of drawn part. Ossama Mamdouh Badr et al [9] experimented the forming of high strength titanium sheet at room temperature. The sheet used is mill annealed cold rolled sheet of thickness 2mm. Specimens of orientation 0°, 45° and 90° t rolling direction were cut. Ti-6Al-4V has limited formability and sudden fracture without distinct neck and has high tendency for spring back. Roll forming has improved spring back effect than witnessed in simple bending and also leads to less shape defects than high strength steel. Nitin Kotkunde et al [10] experimented the influence of material models on theoretical forming limit diagram prediction for Ti-6Al-4V alloy under warm condition. Hybrid FLD using Barlat and Hill yield models with m-Arr hardening model is best to predict theoretical necking limit for Ti-6Al-4V alloy at 400°C. Young-Suk Kim et al [11] investigated prediction of forming limit curve for pure titanium sheet in which commercially pure titanium used in heat exchanger due to its light weight, high specific strength and excellent corrosion resistance. The application of Kim-Tuan model proposed in this work can well predict the forming limit curve from punch stretching test of the pure titanium sheet. Anoop Kumar Shukla et al [12] evaluated experimentally the influence of temperature on nature of fracture in formability test of alpha-beta titanium alloy in which formability tests are done based on alpha-beta titanium alloy using Erichsen cupping test under different tribological conditions at varying temperatures. In this study, blank thickness, lubricants, blank holding force & temperature combination for minimum fracture occurrences are identified at varying temperature. Apostolos N. Chamos et al [13] investigated tensile behavior and formability of Titanium-40 material based on the forming limit diagram approach. Tests are done in two parts one performing tensile tests in which effect of strain rate, material axes orientation along with hardening characteristics as well as anisotropy parameters. The second involves formability limits using Nakazima test and the resulting FLD are compared against each other tests. Work hardening responses observed for the specimens tested in rolling directions. Hossein Mamusi et al [14] presented a novel approach to the determination of forming limit diagrams for tailor weld banks where low carbon steel blanks of various thickness of laser welded stretched using hemispherical die. Case studies include different thickness of same material and different material with same thickness and three criteria's second time derivative of major, thickness strain and equivalent plastic strain used to detect start of necking and FLD's. M.M Moshkar et al [15] investigated the influence of lubrication on strain limits and fracture site in the deformation samples of Al 3105 sheet. The study reveals that out-plane FLD is higher than in-plane FLD. In square sheets, the flow localization and failure occurred near flange under poor lubrication and the same observed at pole for well lubricated such that limiting strains increase with good lubrication. The literature study revealed the gap in the formability studies of Ti-Gr2 sheet. It is found there is enough scope to identify the

Erichsen cupping number in different sheet thickness and study the effect of lubrication on Erichsen cupping number.

II. COMPOSITION & MECHANICAL PROPERTIES

The Ti-Gr2 sheet is widely used in applications such as orthopaedics, aerospace industry, marine chemicals parts and heat exchangers. The chemical composition and mechanical properties of Ti-Gr2 sheet used in this work is shown in Table 1 and Table 2.

Table 1. CHEMICAL COMPOSITION OF TI-GR2 SHEET

Constituents	C	N	O	I	H	Ti
Wt %	0.08	0.03	0.25	0.30	0.015	99.3

Table 2. MECHANICAL PROPERTIES OF TI-GR2 SHEET

Properties	**Metric**
Tensile Strength	485 Mpa
Yield Strength	345 Mpa
Elastic Modulus	105-120 Gpa
Elongation at break	28 %

III. METHODOLOGY

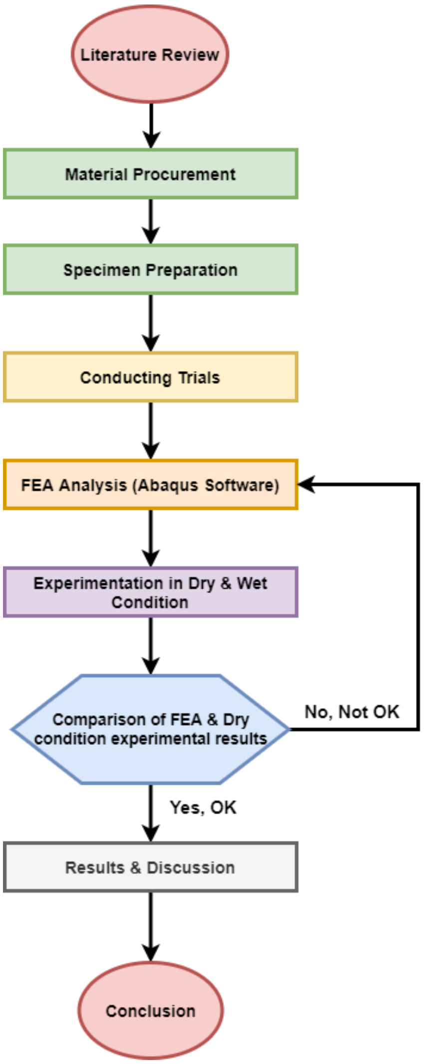

FIGURE 1. Framework of activities in the research work

Figure 1 indicates the methodology followed in this work. In the literature review stage, the papers related to the research work. The formability studies on the sheet metal were collected. The problem definition was framed. The Ti-Gr2 sheet is procured in sheet thickness range of 0.5mm, 1mm and 1.5mm. The specimen was prepared for the Erichsen test with dimensions 90 x 90 mm. The sheets of different thickness were grid printed. Trials indicated Erichsen cupping test machine feasibility of conducting cupping test on the material. The FEA simulation was carried using software (Abaqus v. 6.13). Also, the experiment is conducted physically using Model: MET 20 Erichsen cupping machine in dry and wet condition to check the effect of lubrication SL320 synthetic oil on the cupping height. The results obtained in dry condition was compared with FEA results. In case, the FEA and experiment observation are similar, results are discussed. If deviation observed the FEA simulation will be repeated until the results are in agreement. Finally, conclusion is discussed.

A. ERICHSEN CUPPING TEST AND SPECIFICATIONS

The cupping test machine available at Near Net Shape Laboratory is MET-20 model and is a manual type cupping test machine. The test setup and specifications are shown in Figure 2 and Table 3.

FIGURE 2. CUPPING TEST MACHINE MET 20-MODEL

Table 3. MET 20 MODEL AND SPECIFICATIONS

S.No	Description	Value (Approx.)
1	Make	Meta Test Instruments Pvt. Ltd
2	Width of the sample	70-90 mm
3	Thickness of the sample	0.1-2 mm
4	Least count on micrometric device	0.01/0.02 mm
5	One turn of hand wheel	1.25 mm
6	Overall dimensions	450x500x500 mm
7	Bottom plate	245x255 mm
8	Screw holes in bottom plate	12 mm
9	Distance on screw centre	220x200 mm

B. TEST WORKING PRINCIPLE

The Erichsen cupping test is a ductility test, which is employed to evaluate the ability of metallic sheets and strips to undergo plastic deformation in stretch forming. The test consists of forming an indentation by pressing a punch with a spherical end against a test piece clamped between a blank holder and a die, until a through crack appears. The depth of the cup is measured. The height of the dome is considered as index of drawability. The schematic diagram is shown in Figure 3.

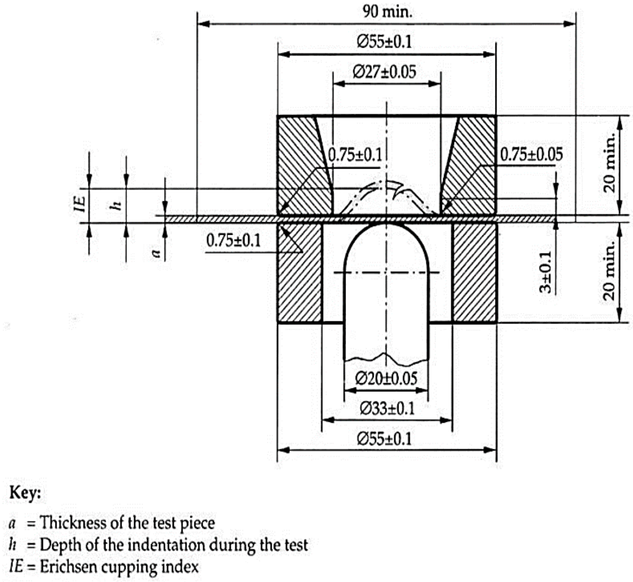

FIGURE 3 SCHEMATIC DIAGRAM OF ERICHSEN CUPPING TEST

IV. SIMULATION RESULTS

The Ti-Gr2 sheet finite element simulation of Erichsen cupping test was used to identify fracture zones and compare with experimentation. The modelling of the setup is carried out in FE software Abaqus 6.13 which includes following components like die, blank holder, punch and sheet. In Abaqus 6.13, after the modeling is completed the next step consists of assigning the material, boundary conditions, mesh, constraints, solving and results. The material properties are assigned based on the properties of Ti-Gr2 sheet. The post results show the sheet deformed state in which the area (red color) represents the maximum stress levels of the sheet in Figure 4 & Figure 7. Isometric view of the sheet is shown in Figure 5 & Figure 8 indicating different stress bands in the deformed sheet. The plot results are based on the node selection from the area of critical region (red color area) shown in Figure 6 & Figure 9. represented through a small red color box. The maximum principal stress and principal strain is shown in Figure 12 & Figure 13. The graph is plotted based on the simulation results which indicates that strain limit of 1.5 mm sheet seems to be comparatively lower than 1 mm sheet. The sheet continues to deform and stress values suddenly drops which directly represents the fracture of the sheet (red color area). The 0.5mm thickness sheet fractures at the blank holding area and hence it is neglected from the simulation concentrating mainly on 1mm and 1.5mm thickness sheet. The sheet yields, undergoes plastic deformation and indicates maximum stress at the red zone in 1mm and 1.5mm sheet thickness.

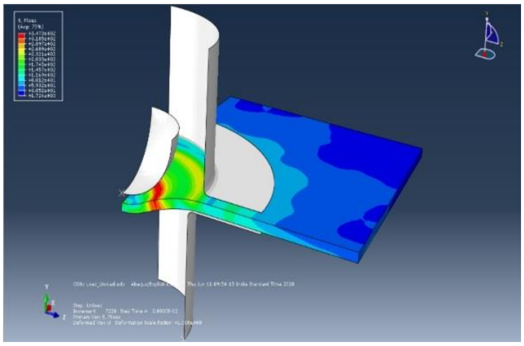

FIGURE 4. DEFORMATION OF 1.5 mm TI-GR2 SHEET

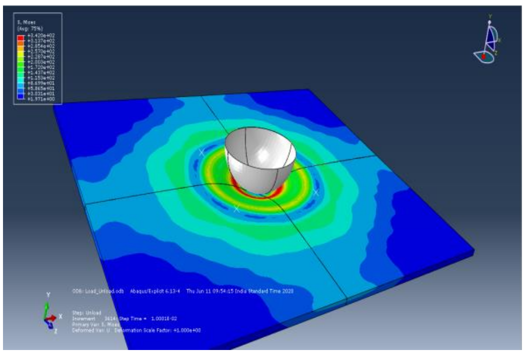

FIGURE 5. DEFORMED 1.5 mm TI-GR2 SHEET ISOMETRIC VIEW

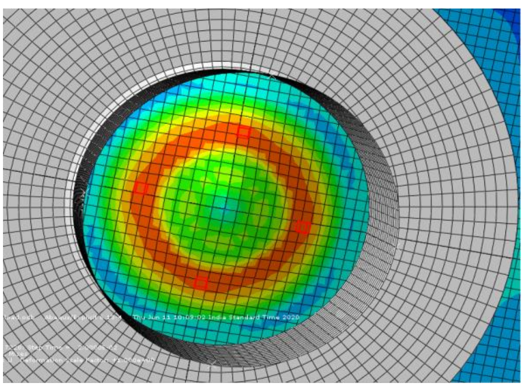

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FIGURE 6. NODE SELECTION (RED COLOR BOX) 1.5 mm THICKNESS SHEET

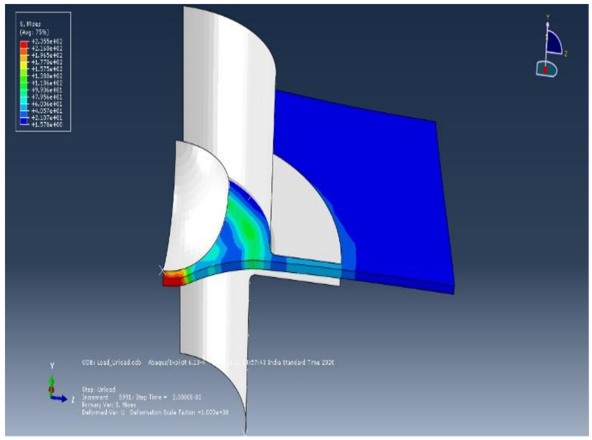

FIGURE 7. DEFORMATION OF 1 mm TI-GR2 SHEET

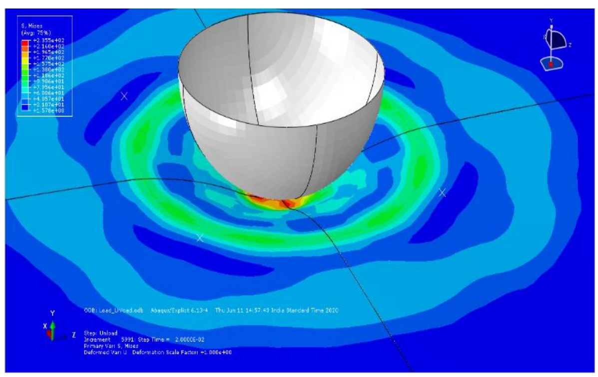

FIGURE 8. DEFORMED 1 mm TI-GR2 SHEET ISOMETRIC VIEW

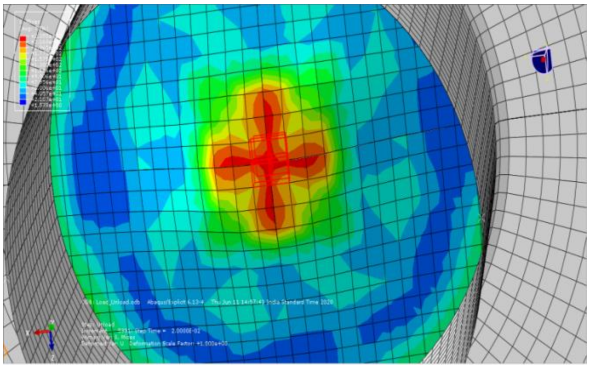

FIGURE 9. NODE SELECTION (RED COLOR BOX) 1 mm THICKNESS SHEET

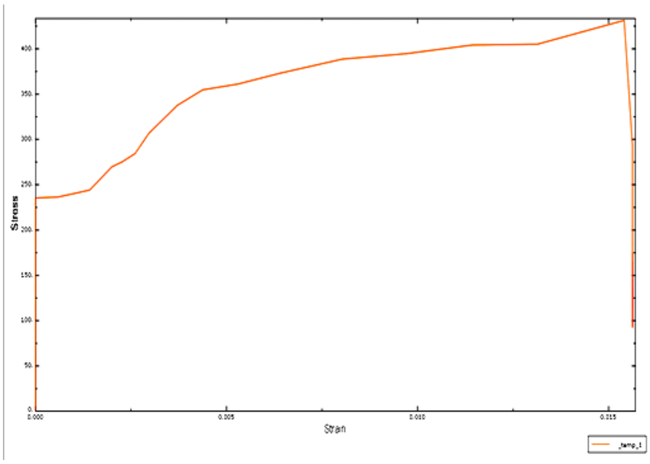

FIGURE 10. STRESS VS STRAIN GRAPH OF 1.5mm TI-GR2 SHEET

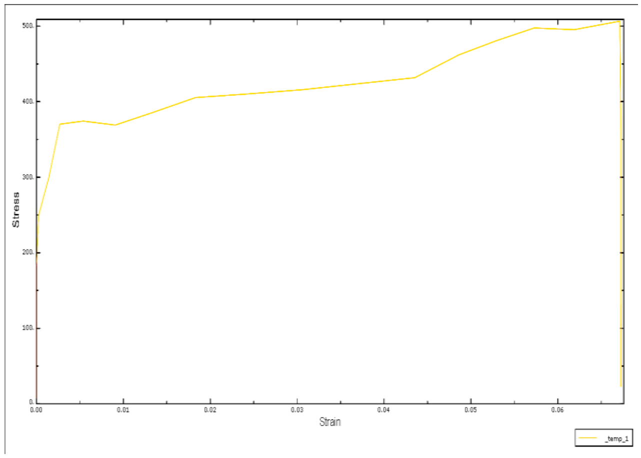

FIGURE 11. STRESS VS STRAIN GRAPH OF 1 mm TI-GR2 SHEET

V. EXPERIMENTAL RESULTS

The specimen of Ti-Gr2 sheet of dimension 90x90 mm with three different thickness of 0.5mm, 1mm, 1.5mm are tested. The vernier and main scale reading is noted as the fracture appears in the different sheet thickness of Ti-Gr2 sheet and the readings are noted as Erichsen Cupping Number (cupping height). The cupping height obtained from the test is tabulated. The sheet thickness of 0.5 mm deformed indicates that fracture appeared in the holding area of the punch and die. The reason is low thickness results in the thinning which happens at the base of the holding area at the juncture of punch and die.

The sheet thickness of both 1mm and 1.5mm undergo uniform plastic deformation and fracture occurs at cup region. The sheet thickness of 1mm and 1.5mm thickness sheet produced better results compared with 0.5 mm in cupping test. The Table 4 represent the values of the Erichsen cupping height obtained in three consecutive trails for Ti-Gr2 sheet of thickness 0.5mm, 1mm, 1.5mm under dry and wet condition. The average value of Erichsen cupping number for all the three thickness is tabulated along with trials and it shows that there is a significant rise in cup height when thickness of the sheet is increased in both dry and wet condition. Comparison of dry and wet condition results indicate that there is a significant difference in cupping height as a consequence of applying lubricant it is possible that further increase in cup height is observed due to certain factors like decrease in friction and heat produced.

Table 4. ERICHSEN CUPPING NUMBER IN DRY AND WET CONDITION

S.No.	Erichsen No.-Dry Condition			Erichsen No.-Wet Condition		
	0.5 mm	**1 mm**	**1.5 mm**	**0.5 mm**	**1 mm**	**1.5 mm**
1	16.018	17.011	18.018	16.045	18.015	18.03
2	16.033	17.028	18.031	16.049	18.014	18.025
3	16.011	17.023	18.022	16.056	18.017	18.042
Avg	**16.02**	**17.02**	**18.02**	**16.05**	**18.02**	**18.03**

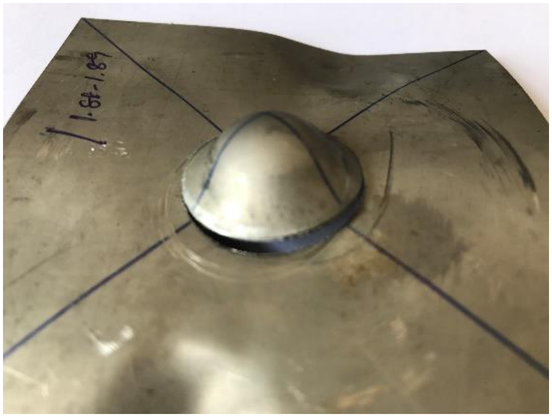

FIGURE 12. FRACTURE IN 0.5 mm THICKNESS SHEET-DRY CONDITION

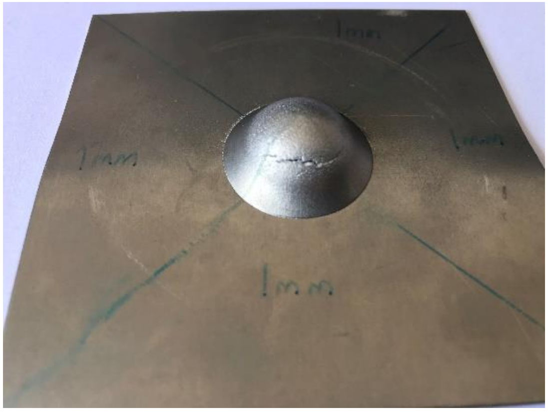

FIGURE 13. FRACTURE IN 1 mm THICKNESS SHEET-DRY CONDITION

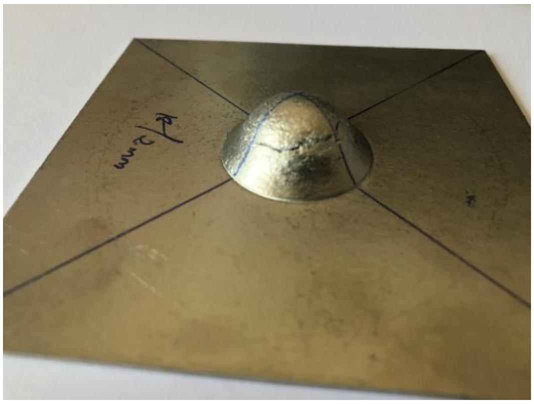

FIGURE 14. FRACTURE IN 1.5 mm THICKNESS SHEET- DRY CONDITION

FIGURE 15. FRACTURE IN 0.5 mm THICKNESS SHEET- WET CONDITION

mm thickness sheet. In the graph, the bottom and top point of the curve coincide indicating influence of lubrication on Erichsen number is the 1mm sheet thickness of Ti-Gr2 sheet.

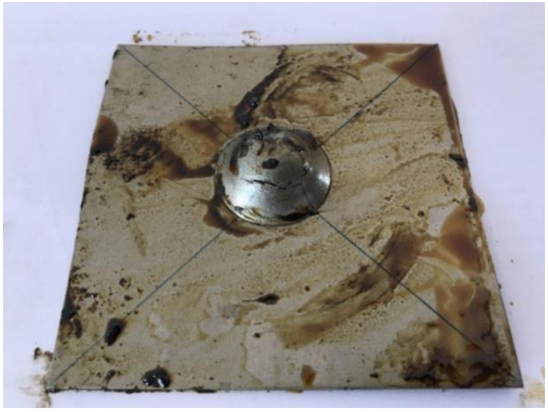

FIGURE 16. FRACTURE IN 1 mm THICKNESS SHEET- WET CONDITION

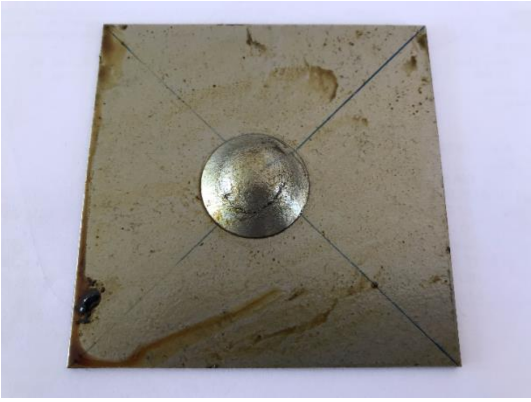

FIGURE 17. FRACTURE IN 1.5 mm THICKNESS SHEET- WET CONDITION

Figure 12, 13 & 14 indicate the dry formed samples. Figure 15, 16 & 17 represent the wet formed samples in Erichsen Cupping test.

A. SHEET THICKNESS VS ERICHSEN CUPPING NUMBER

Formability of Ti-Gr2 sheet in dry and wet condition is tested and Erichsen cupping number of sheet for different thickness under wet and dry condition is identified. Figure 18 represents change in Erichsen number with respect to the sheet thickness in dry and wet condition. Erichsen number is same at lower and high sheet thickness .The impact of SL320 synthetic oil on the Erichsen cupping number is found in the 1 mm thickness sheet. In the graph, the bottom and top point of the curve coincide indicating influence of lubrication on Erichsen number is the 1mm sheet thickness of Ti-Gr2 sheet.

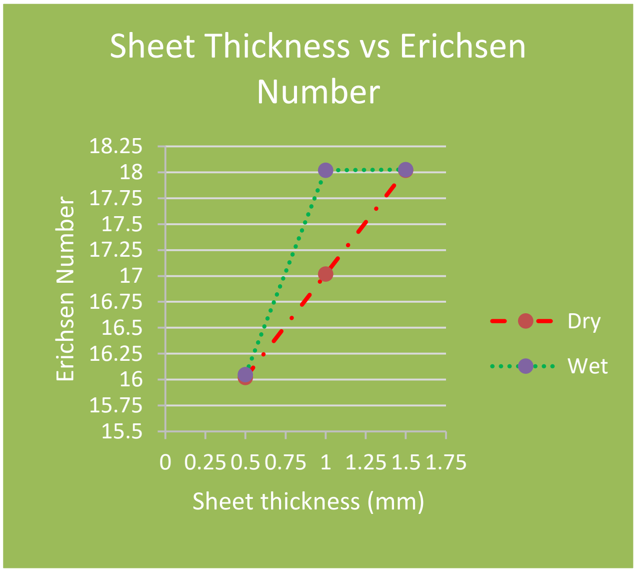

FIGURE 18. SHEET THICKNESS VS ERICHSEN CUPPING NUMBER FOR WET AND DRY CONDITION

V. CONCLUSION

In this work, the chemical composition and mechanical properties of Ti-Gr2 sheet is discussed. The room temperature formability of Ti-Gr2 sheet is tested with the MET-20 model Erichsen testing machine. The following are the results summarized in this work.

1. The FE simulation indicated the weak zone in 1 and 1.5 mm sheet thickness of Ti-Gr2 sheet.
2. Stress strain graph plotted from the FE simulation of Ti-Gr2 sheet indicates that strain limit of 1.5 mm sheet to withstand the fracture is less compared to 1mm. The sheet continues to deform and stress values suddenly drops which directly represents the fracture of the sheet.
3. The Erichsen cupping number of 1 and 1.5 mm sheet was found to be 17.02 and 18.02 in dry condition.
4. The influence of lubrication increased the formability in 1 mm Ti-Gr2 sheet from 17.02 to 18.02 mm.
5. The Erichsen cupping number of 0.5mm thickness is 16.02 and found the sheet has poor formability as it

Acknowledgments

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