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Formability of 5083 Al Alloy Hemi-Spherical Shells Using Hot Deep Drawing Process

A. Chennakesava Reddy

Professor, Department of Mechanical Engineering, JNT University Hyderabad, India.
E-mail: chennakesava@jntuh.ac.in

Abstract

5083 is highly resistant to attack by both seawater and industrial chemical environments and is being used for fabrication pressure vessels. Most of pressure vessels have spherical domes. The current work was interested to explore the formability of hemi-spherical shells from 5083 Al alloy using hot deep drawing process. The major process variables, which would control the stress induced during the drawing of hemi-spherical cups, were temperature and strain rate. The damage factor was influenced by the coefficient of friction. Except local burnishing lower-middle portion of the side walls, the formability of hemi-spherical cups has been found excellent.

Keywords: 5083 Al alloy, Hemi-spherical cups, temperature, strain rate, coefficient of friction

1. INTRODUCTION

Due to its lightweight and high specific strength, aluminum (Al) alloys are these days very potential for aerospace, automobile, shipbuilding, and domestic applications. In 5XXX series aluminum alloys, the major alloying element is magnesium (Mg). Among 5XXX series aluminum alloys, 5083 is highly resistant to attack by both seawater and industrial chemical environments [1]. 5083 Al alloy is used in the manufacture of unfired, welded pressure vessels, marine, auto aircraft cryogenics, drilling rigs, TV towers, transportation equipment, and in missile components.

A spherical shape is difficult to manufacture. Spinning, explosive forming and hydroforming are being used to manufacture hemi-spherical shells. Spinning is used widely in practice for manufacturing of hemi-spherical shells. Difficulties in maintaining uniform thickness and geometry tolerances have been encountered with this technique [2]. Explosive forming of shell fabrication requires mold and press which leads to higher costs of production. Fabrication of thin spherical shells is another great task in explosive forming [3]. The spherical shells are fabricated by plastic expansion in the hydroforming. In spite of several advantages of hydroforming process, the production cycle is very long. In this paper, the hot deep drawing process has been attempted to fabricate hemi-spherical shells. In this process, the sheet metal is pushed through the die, which possesses the shape of the product to be drawn [4, 5]. In hot deep drawing process, the formability is strongly dependent upon alloy composition, temperature, strain rate, and coefficient of friction [6, 7]. An able approach for the enhancement of formability is performing the forming processes at elevated temperatures up to the recrystallization temperature [8, 9]. During the hot tensile deformation, the level of flow curve increases with increasing of strain rate and decreases with changing temperature.

The aim of the current work was to investigate the formability of hemi-spherical shells from 5083 Al alloy using hot deep drawing process. The hot deep drawing process was executed using 3D-DEFORM software. The design of experiments was carried out using Taguchi's techniques.

2. MATERIALS AND METHODS

5053 aluminum alloy consists of: Al (93.43%), Mg (4.5%), Mn (0.8%), Cr (0.15%), Si (0.40%), Fe (0.40%), Cu (0.10%), Ti (0.12%), and Zn (0.10%). In the present work, 5083 Al alloy was used to make cylindrical cups. The sheets of 5083 Al alloy were cut to the required blank size of circular shape. The levels chosen for the controllable process variables are summarized in table 1. The finite element analysis (FEA) was implemented as per the Taguchi's design of experiments [10] using orthogonal array, L9. The assignment of parameters in the OA matrix is given in table 2.

Table 1: Control parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Temperature, ^{0}C	A	300	400	500
Strain rate, 1/s	B	0.1	0.5	1.0
Coefficient of friction	C	0.10	0.15	0.20
BH velocity, mm/s	D	0.13	0.`7	0.20

Table 2: Orthogonal array (L9) and control parameters

Treat	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

D-FORM 3D software was employed to carry out the finite element modeling and analysis. The circular sheet blank was created with desired diameter and thickness using CAD tools as defined in [1]. The cylindrical top punch, cylindrical bottom hollow die was also modeled with appropriate inner and outer radius and corner radius using CAD tools. The clearance between the punch and die was calculated as in Eq. (1). The sheet blank was meshed with tetrahedral elements. In the present work, moving blank die was used to hold the blank at a predefined speed different to the punch speed. The contact between blank/punch and die/blank were coupled as contact pair with the Coulomb’s friction model as defined in Eq. (2).

Clearance, $$c = t \pm \sqrt{10t} \qquad (1)$$

The Coulomb’s friction model was given by

$$\tau_f = \mu p \qquad (2)$$

3. RESULTS

Results of ANOVA tests clearly revealed (Table 3) that the variables of temperature and strain rate had significant ($F > F_{10,\, v1,\, v2}$) effect on the von Mises stress developed during the hemi-spherical cup drawing process. Reduction in the von Mises stress with respect to the temperature increment to soften 5083 Al alloy is well in agreement with the gradient of curve as shown in figure 1. The reduction in the von Mises stress was 149.33 MPa on account of raise in the temperature from 300°C to 500°C. Similarly, hike in the von Mises stress with respect to the strain rate increase to strain harden 5083 Al alloy is shown in figure 1 during its plastic deformation to form the cup. The augmentation in the von Mises stress was 118.67 MPa due to raise in the strain rate from 0.1 s^{-1} to 1.0 s^{-1}. Though the coefficient of friction could generate heat between the sheet blank and the dies or could restrict the flow of sheet material during the hemi-spherical cup drawing process, its magnitude was insufficient either to soften or strain harden 5083 Al material. The influence of friction coefficient is statistically insignificant to cause variation in the von Mises stress as observed from Table 3.

Table 3: ANOVA results of the von Mises stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	2551.00	2387.00	2103.00	34250.67	2	17125.33	6.18	43.21
B	2249.00	2187.00	2605.00	33922.67	2	16961.33	6.12	42.80
e_{pooled}	2505.00	4571.00	4846.00	11088.67	4	2772.17		13.99
T				79262.00	8			100.00

Note: SS is the sum of square, v is the degrees of freedom, V is the variance, F is the Fisher's ratio, P is the percentage of contribution, ep is the pooled error, and T is the sum squares due to total variation.

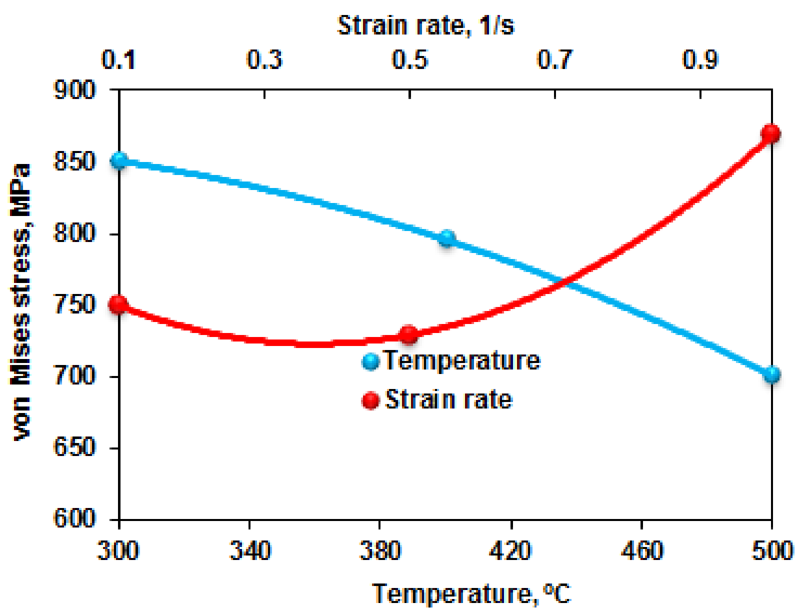

Figure 1: Effect of temperature on von Misses stress in the hemi-spherical cup.

The hemi-spherical cups, of the 9 trials, did not experience any damage due to increase in temperature and strain rate during the deep drawing process. Both temperature and strain rate are statistically insignificant on the damage factor of the hemi-spherical cups as mentioned in Table 4. However, there exists the influence of friction coefficient ($F > F_{5,\ v1,\ v2}$) on the damage factor of the hemi-spherical cups as cited in Table 4. If not tears or cuts in the hemi-spherical cups, the worn spots were noticed on the side walls of the hemi-spherical cups drawn of the trials wherein the coefficient of friction was 0.15. Because of such phenomena, the damage factor is high at 0.15 value of friction coefficient as shown in figure 2. An increase in the coefficient of friction from 0.10 to 0.15 would intensify the damage factor by 62.50%. Otherwise, a decrease in the coefficient of friction from 0.20 to 0.15 would amplify the damage factor by 70.84%.

Table 4: ANOVA results of the damage factor

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
C	0.49	0.79	0.46	0.0224	2.00	0.0112	9.78	60.41
ep	1.74	1.75	1.74	0.0069	6.00	0.0011		18.52
T				0.0371	8.00			100.00

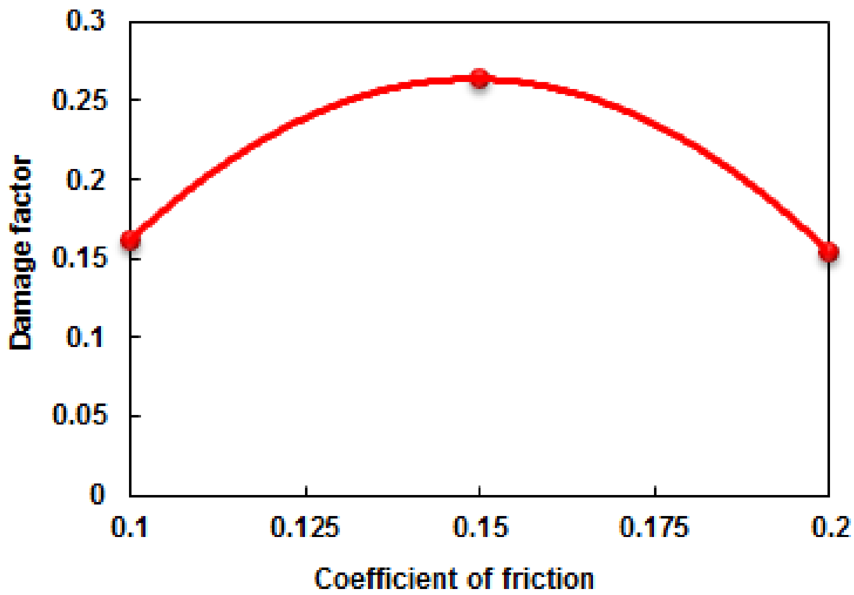

Figure 2: Effect of friction coefficient on damage factor of the hemi-spherical cups.

4. DISCUSSION

From the results mentioned, it appears that the temperature and the strain rate affect the von Mises stress developed during the plastic deformation of 5082 Al alloy to form the hemi-spherical cups. With respect to temperature, trails 1, 2 and 3 are belonging to 300°C; trails 3, 4 and 5 are belonging to 400°C; and trails 6, 7 and 8 are belonging to 500°C. As the temperatures increases from 300°C to 500°C the von Mises stress decreases from 850 MPa to 701 MPa as shown in figure 3a. With respect to strain rate, trails 1, 4 and 7 are belonging to 0.1 s^{-1}; trails 2, 5 and 8 are belonging to 0.5 s^{-1}; and trails 3, 6 and 9 are belonging to 1.0 s^{-1}. The von Mises stress increases from 750 MPa to 868 MPa due to an increase in the strain rate from 0.1 s^{-1} to 1.0 s^{-1}. Nearly, the same kind of trend is also observed from the punch load v/s stroke length curves of the 9 trails as shown in figure 3b. In case of 5xxx Al alloys it has been revealed that Mg atoms exert a higher effect on the strain hardening than on the solution strengthening [12]. The ductility decreases with increasing content of Mg in 5xxx Al alloys. In the present work, this is similar to the effect of decreasing temperature or increasing strain rate during the hemi-spherical cup drawing process (figure 4).

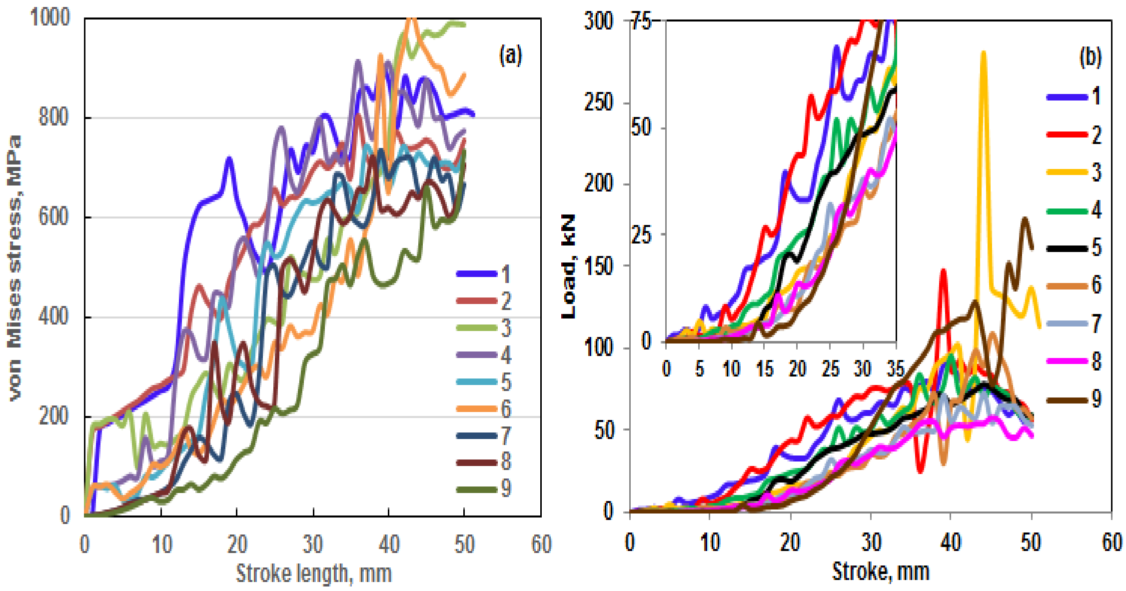

Figure 3: FEA results for all the trials of hemi-spherical cups: (a) von Mises stresses and (b) stroke vs load.

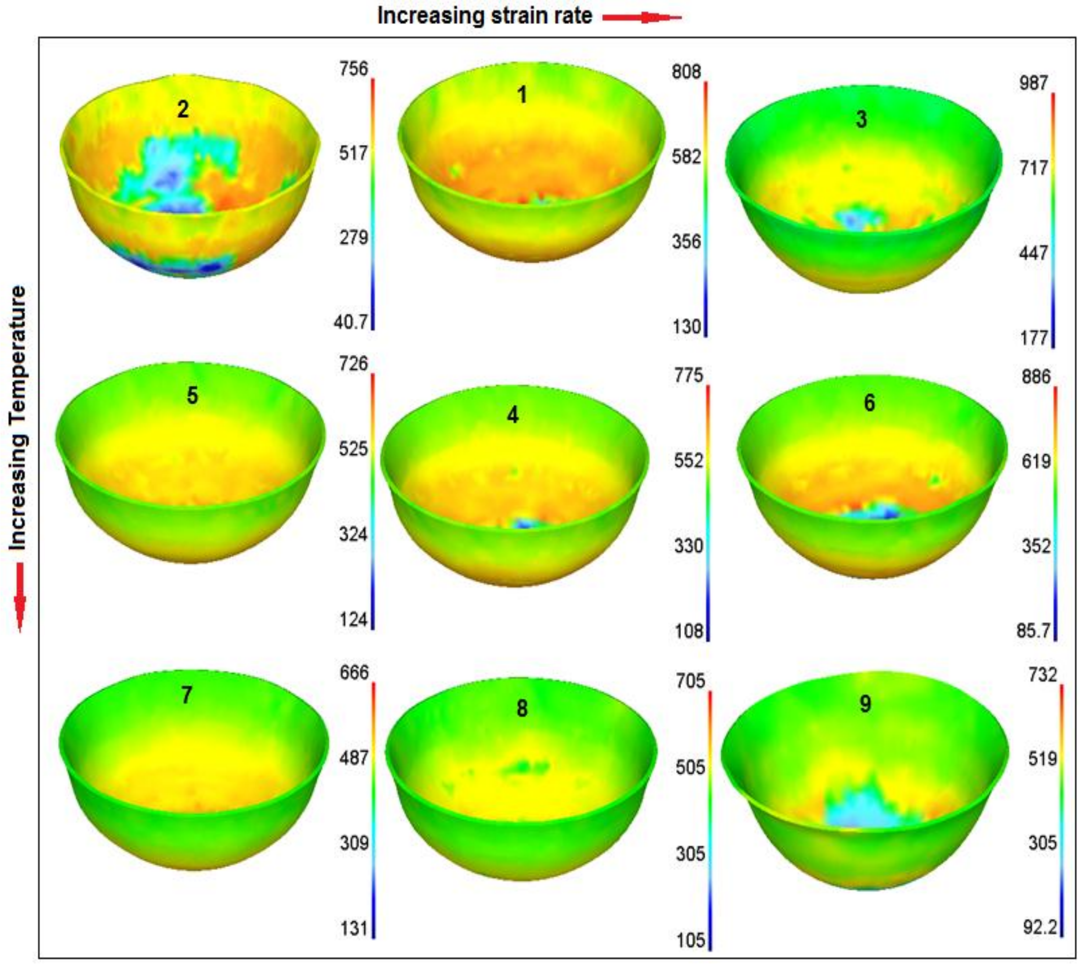

Figure 4: The von Mises stresses induced in the hemi-spherical cups.

The formability of hemi-spherical cups drawn from 5083 Al alloy for the 9 trials is shown in figure 5. The formability trend is nearly the same for all the cases of nine trials. The formability is totally influenced by the mechanism of shear localization. The hemi-spherical cup fabricated with trial-7 conditions is shown in figure 5(d). Except little burnishing at the lower-middle portion of hemi-spherical cup, the yield of the cup is excellent. The damage factor is high for the trial-1 and trial-9 conditions and least for trai-3 and trial-6 conditions. Even though the damage factor was low for trai-3 and trial-6 conditions, the burnishing was very high with elongated grains on the side walls of the hemispherical cups. Grain size has also a significant influence on the strain rate and temperature during the superplastic deformation process [13, 14]. Local thinning [15] was also noticed on side walls of the cups drawn with trial-1 and trail-9 conditions.

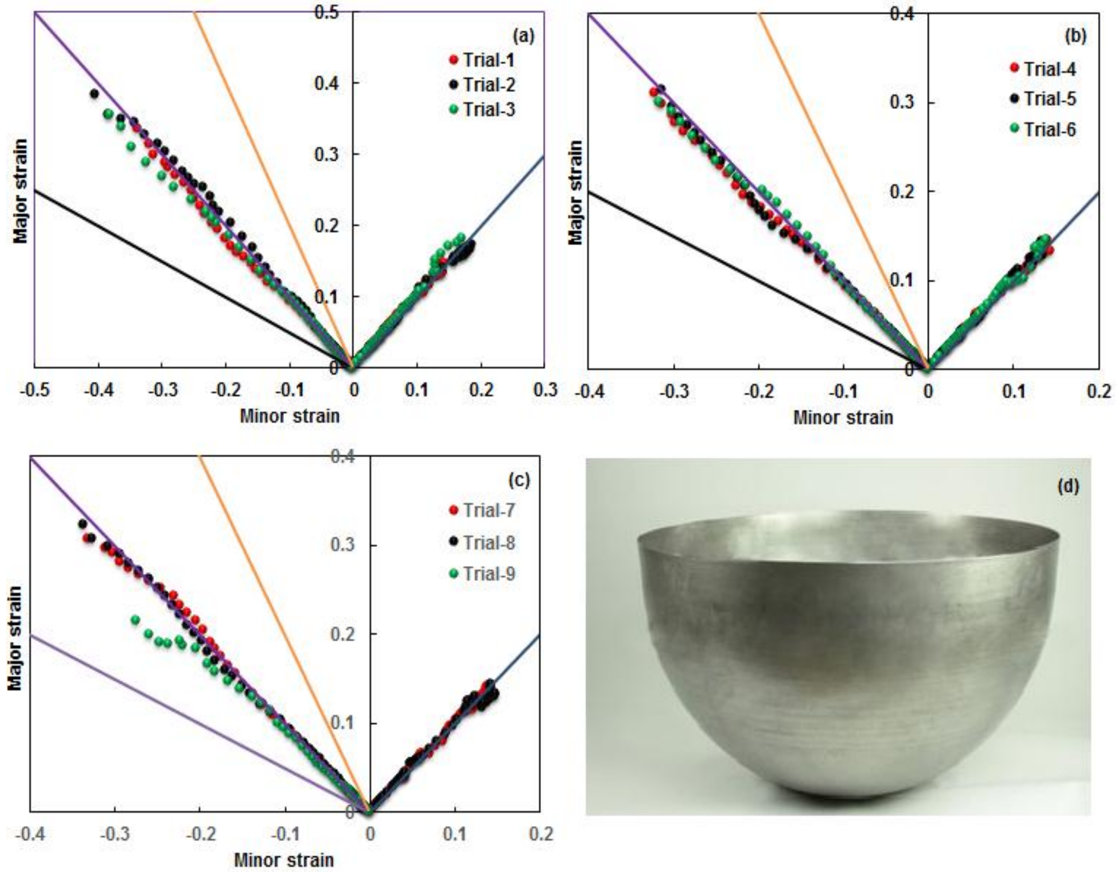

Figure 5: Formability diagrams of hemi-spherical cups.

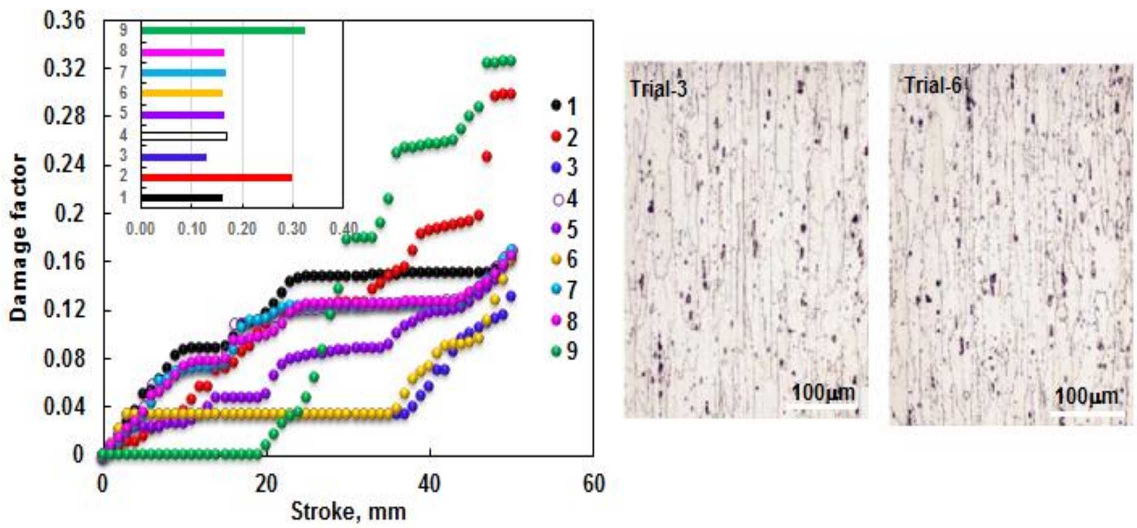

Figure 6: Damage factors of hemi-spherical cups.

5. CONCLUSION

The present findings thus, indicate that the temperature and strain rate are very critical on the plastic deformation of hemi-spherical cups without rupture. The coefficient of friction promotes the burnishing phenomena on the side walls of the hemi-spherical cups. The formability is nearly same for all the cups drawn with conditions as per the design of experiments in this work. The formability is absolutely influenced by the mechanism of shear localization.

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REFERENCES

[1] Aalco-Metals-Ltd_Aluminium-Alloy-5083.
[2] Babcock, C. D., 1983, "Shell Stability," ASME Journal of Applied Mechanics, 50(4b), pp. 935–940.
[3] Zhang, T., 1992, "Explosive forming of spherical metal vessel without die," Journal of Material Processing Technology, 31, pp.135–145.
[4] Reddy, A. C., Reddy, T. K. K., and Vidya Sagar, M., 2012, "Experimental characterization of warm deep drawing process for EDD steel," International Journal of Multidisciplinary Research & Advances in Engineering, 4(3), pp.53-62.
[5] Alavala, C. R., 2016, "Development of High Temperature and High Strain Rate Super Plastic Deep Drawing Process for 5656 Al Alloy Cylindrical Cups," International Journal of Mechanical and Production Engineering, 4(10), pp. 187-193.
[6] Alavala, C. R., 2016, "Effect of Temperature, Strain Rate and Coefficient of Friction on Deep Drawing Process of 6061 Aluminum Alloy," International Journal of Mechanical Engineering, 5(6), pp. 11-24.
[7] Reddy, A. C., 2015, "Performance of Warm Deep Drawing Process for AA1050 Cylindrical Cups with and Without Blank Holding Force," International Journal of Scientific Research, 4(10), pp. 358-365.
[8] Horita, Z., Furukawa, M., Nemoto, M., Barnes, A. J., and Langdon, T. G., 2000, "Superplastic forming at high strain rates after Severe plastic deformation," Acta Materialia, 48, pp. 3633–3640.
[9] Reddy, A. C., 2015, Homogenization and Parametric Consequence of Warm Deep Drawing Process for 1050A Aluminum Alloy: Validation through FEA, International Journal of Science and Research, 4(4), pp. 2034-2042.

[10] Reddy, A. C., and Shamraj, V. M., 1998, “Reduction of cracks in the cylinder liners choosing right process variables by Taguchi method,” Foundry Magazine, 10(4), 47-50.

[11] Alavala, C. R., 2016, High temperature and high strain rate superplastic deep drawing process for AA2618 alloy cylindrical cups, International Journal of Scientific Engineering and Applied Science, 2(2), pp. 35-41.

[12] Lloyd, D.J., 2006, “Materials Science Forum,” pp. 519–521.

[13] Wilkinson, D. S., Caceres, C. H., 1984, “On the mechanism of strain-enhanced grain growth during superplastic deformation,” Acta Metallurgica, 32, pp. 1335-1345.

[14] Alavala, C. R., 2016, “Suitability of High Temperature and High Strain Rate Superplastic Deep Drawing Process for AA5052 Alloy,” International Journal of Engineering and Advanced Research Technology, 2(3), pp. 11-14.

[15] Reddy, A. C., 2012, “Evaluation of local thinning during cup drawing of gas cylinder steel using isotropic criteria,” International Journal of Engineering and Materials Sciences, 5(2), pp. 71-76.