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Formability of Heat Treated AA19000, AA5052 and Simulation using ABAQUS/CAE

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ABSTRACT:

In this paper the formability of heat treated AA19000 and AA5052 aluminium alloys was studied through experimentation and finite element simulation. The aluminium alloys of 1mm thickness as received and annealed condition were subjected to tensile test and Erichsen cupping test. The experimental results showed that AA5052 possessed better formability than AA19000, due to its magnesium content. The material properties obtained from the tests were validated through simulation using ABAQUS/CAE.

KEYWORDS:

Tensile test; Annealing; Formability; Erichsen cupping test; ABAQUS/CAE

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1. Introduction

The method of modifying the geometry of a sheet metal without tearing is specifically known as sheet metal forming. Due to this behaviour the forming process is used widely to form variety of complex shapes. Formability of sheet metal is determined by conducting two different tests such as tensile test and erichsen cupping test. The aluminium alloys have high improved properties like corrosion resistant nature and very improved strength to weight ratio, corrosion. The formability behaviour of aluminium sheets has complex shapes such as automotive body parts [1]. The cold rolled sheet metal product have been used in various industries in development of the microstructure complexities such as formation of different textures produced through rolling and imparting rolling and anisotropic properties [10]. Anisotropy plays an important role in the sheet forming processes. The main reason of anisotropy in metals is due to better orientation of grains which forms during rolling, i.e. statistical orientation of grains in any specific cross section with special crystallographic directions [11]. The formability is based on stress and not of strain.

The recrystallization during annealing process usually changes the crystallographic texture, but does not randomize it [9]. In sheet metal forming plastic deformation often occurs in certain crystal planes, and thus the crystal planes are bended and rotated a well-known orientated texture called deformation texture is created [14]. The texture of metal formed after deformation is influenced by the mode of deformation and the temperature during forming [13]. The tensile test is conducted in Universal Testing Machine (UTM,) were the tensile strength found out from stress versus strain graph obtained from the test. The erichsen cupping test is a stretch formability test which simulates plane biaxial tensile deformation. The Erichsen test is conducted by firmly clamping the sheet metal between the blank holders. The clamping is done in order to prevent the feeding of the sheet metal into the deformation zone during testing [2]. The ball punch is forced onto the sheet specimen during the erichsen cupping test and the force is will drawn as stopped immediately after the crack appear in the dome of the bulge. The erichsen drawing index (IE) is the distance travelled by the punch during the erichsen test and is a measure of formability during the stretch forming of a sheet [16].

The automobile industry requires formed sheet metal having light weight and lightly stressed planes, the aluminium alloy sheet metals AA5052 and AA19000 have been widely used. The objective of this project is to find the best material for automotive applications by conducting tensile test and Erichsen cupping test for the sheet metal at un-annealed and annealed conditions. The results from these tests shall be useful to identify the material with good formability parameters like plastic strain ratio and strain hardening index [14]. The result from these two tests is used to simulate the formability using ABAQU/CAE.

2. Experimental procedure

The AA5052 and AA19000 aluminium alloy test specimens were taken at un-annealed and annealed conditions. For the tensile test, three specimens are taken for each direction (i.e. 0°, 45°, 90°) to find the material properties and formability parameters. Annealing is done to refine grains and to relieve internal stress by heating the specimens at 350°C in furnace shown in Fig. 1 for 15 minutes followed by furnace cooling. The furnace has Nichrome coils which can reach a maximum temperature of 1100°C. The tensile specimens were cut from a sheet of 1mm thickness in three different directions namely longitudinal (0°), diagonal (45°), and transverse (90°) to the rolling directions of the sheet metal as per TALAT [2, 7, 14] as shown in Fig. 2. The chemical composition of Aluminium alloys AA19000 and AA5052 are presented in Table 1. Both alloys have good formability, good corrosion resistance and electrical conductivity.

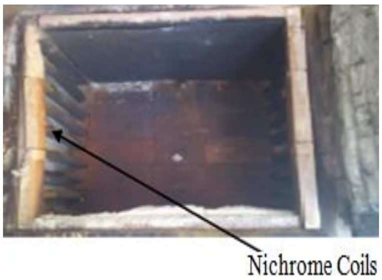

Fig. 1: Annealing furnace

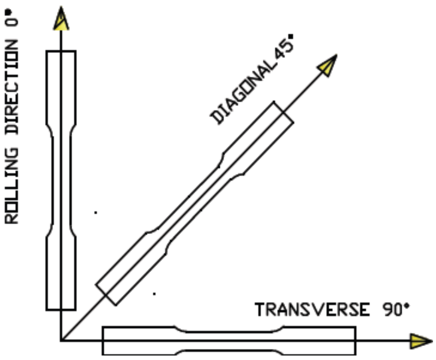

Fig. 2: Preparing tensile specimen from a sheet

Table 1: Chemical composition of AA19000 and AA5052

Alloy	Mg	Cr	Si	Fe	Cu	Mn	Zn	Al
AA19000	-	-	0.50	0.60	0.10	0.10	-	Balance
AA5052	2.8	0.35	0.25	0.40	0.10	0.10	0.10	Balance

The tensile tests were carried out as per ASTM A370 using specimen of 12.5 mm wide with a gauge length of 50 mm as shown in Fig. 3. The extension in length Δl of the tensile test specimens was measured using an extensometer. Specimens were gripped at both ends and pulled at a constant rate of 7mm/min in 40 kN universal testing machine (UTM). All tests were done at room temperature. The strain hardening exponent (n), the plastic strain ratio 'R' and the planar anisotropy 'ΔR' are the parameters of formability of sheet metals. The strain hardening exponent 'n' was found as per ASTM 646 using empirical formula [3, 4]. The outputs from tensile test like state of anisotropy 'R' in three grain directions, Young's modulus 'E', strain hardening index 'n', ultimate tensile strength 'σ_u', yield strength 'σ_y' and density 'ρ' were used in developing a finite element model with a punch and sheet metal.

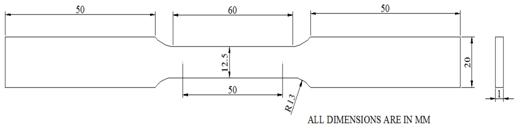

Fig. 3: Tensile specimen as per ASTM A370 standards

The AA5052 and AA19000 aluminium alloy sheets were investigated under Erichsen cupping test to find out the strength, hardness, anisotropy and stretch formability. Erichsen cupping test is conducted because the sheet formability cannot be found with mechanical properties alone. The Erichsen cupping test is conducted as per IS 10175 standard. AA5052 and AA19000 aluminium alloy a sheet of dimension 90 x 90mm is clamped between two ring dies of Erichsen tester and a ball is forced against the sheet until it fractures. The depth of the bulge before fracture is measured using vernier scale. The Erichsen number is calculated as the difference between initial reading and final reading of the bulge as measured in vernier caliper [5].

3. Results and discussions

The stress vs. strain graphs from the tensile tests of AA5052 and AA19000 aluminium alloy sheet metal specimens are shown in Figs. 4 and 5. The tensile properties of annealed and un-annealed AA5052 and AA19000 aluminium alloy were found out by tensile test at room temperature with the axis of specimen oriented at 0°, 45° and 90° of the rolling direction of the sheets are given in Tables 2 to 5. The strength coefficient is given by power law equation $\sigma = k\epsilon^n$, where σ is stress, ϵ is strain and n is strain hardening index.

Table 2: Tensile properties of AA19000 sheet metal specimen at un-annealed condition

Orientation wrt	AA19000 un-annealed			
rolling direction	n	k (MPa)	σ_y (MPa)	σ_u (MPa)
0°	0.252	164.01	116.39	124.35
45°	0.250	168.01	118.32	124.69
90°	0.190	111.42	116.30	123.13
Average	0.231	147.81	117	124.06

Table 3: Tensile properties of AA5052 sheet metal specimen at un-annealed condition

Orientation wrt	AA5052 un-annealed			
rolling direction	n	k (MPa)	σ_y (MPa)	σ_u (MPa)
0°	0.301	343.60	181.64	214.54
45°	0.262	178.31	56.44	89.34
90°	0.176	246.71	118.64	187.82
Average	0.246	256.21	118.91	194.37

Table 4: Tensile properties of AA19000 sheet metal specimen at annealed condition

Orientation wrt	AA19000 Annealed			
rolling direction	n	k (MPa)	σ_y (MPa)	σ_u (MPa)
0°	0.283	135.77	64.30	86.49
45°	0.256	95.91	48.56	61.73
90°	0.196	116.19	61.23	84.08
Average	0.245	115.96	58.03	77.43

Table 5: Tensile properties of 5052 sheet metal specimen at annealed condition

Orientation wrt rolling direction	AA5052 Annealed n	k (MPa)	σ_y (MPa)	σ_u (MPa)
0°	0.331	190.57	102.44	187.07
45°	0.312	134.82	180.44	209.08
90°	0.210	148.08	170.23	186.97
Average	0.284	157.82	151.04	194.37

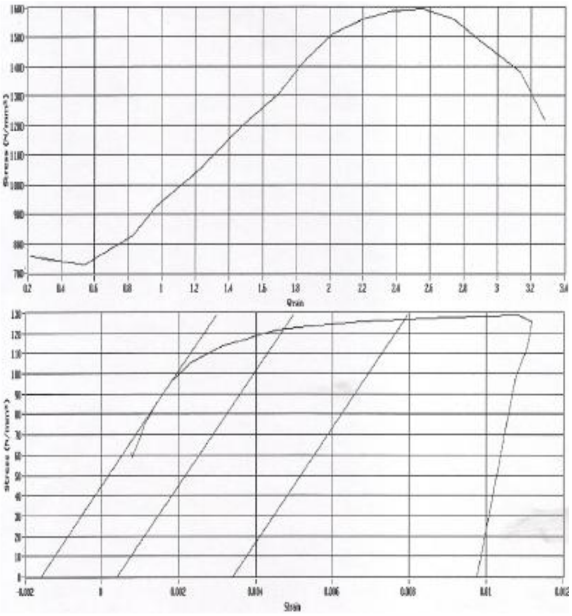

Fig. 4: Stress vs. Strain for AA19000

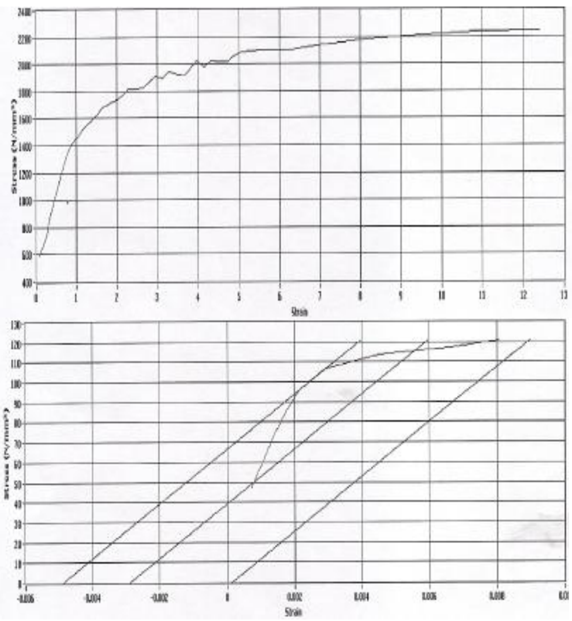

Fig. 5: Stress vs. Strain for AA5052

In the Erichsen cupping test, the stretch formability of the sheet is predicted from Erichsen number or index, from cupping and deep-drawing cup test machine of maximum 100 kN drawing force, 45 kN blank holding force, drawing punch stroke 60mm, blank holder stroke 35mm, blanking force 200 kN, opening for sheet insert 110mm and net weight approximately 350 kg. A photograph of the specimen is shown in Fig. 6. Three trials were taken for both AA19000 and AA5052 at un-annealed and annealed conditions. Their results are shown in Figs. 7 and 8. Maximum Erichsen number from both AA19000 and AA5052 was compared and led to conclude that annealed AA5052 at has produced more stretch formability when compared with AA19000 [13].

Fig. 6: Erichsen cupping specimen of dimension 90mm x 90mm

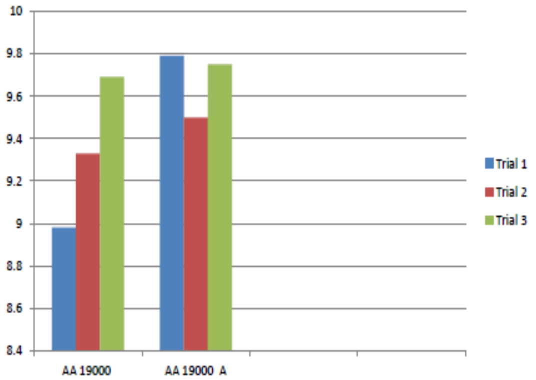

Fig. 7: Erichsen cupping number of AA19000 at un-annealed and annealed conditions

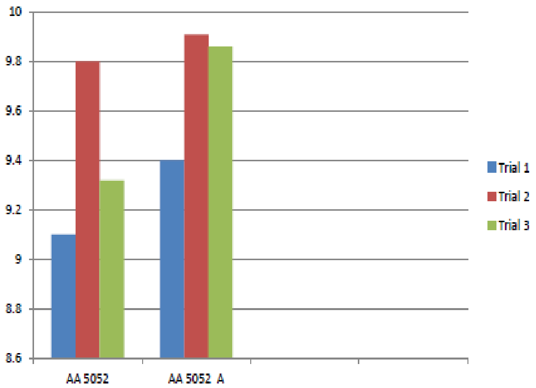

Fig. 8: Erichsen cupping number of AA5052 at un-annealed and annealed conditions

The anisotropic nature of plasticity during formability is presented in Tables 6 to 9. The state of anisotropy is represented by R= $w_0 l_0/wl$. The plastic anisotropy ratio is represented by, $\bar{R} = (r_o + 2r_{45} + r_{90})/4$. The planar anisotropy is represented by $\Delta R = (r_o + r_{90} - 2r_{45})/2$. Where, r_o- longitudinal rolling direction, r_{45} - diagonal, r_{90} - transverse rolling direction, w - change in width, w_o - original width, l - change in length and l_0 - original length.

Table 6: Plastic anisotropy ratio $\bar{R}$ and ΔR of AA19000 un-annealed and annealed conditions

Orientation relative to rolling direction	AA 19000 at un-annealed condition R	nR	$\bar{R}$	ΔR
0°	1.430	0.360	1.1	1.74
45°	0.200	0.050		
90°	2.441	0.463		
Average	1.36	0.291		

Table 7: Plastic anisotropy ratio $\bar{R}$ and ΔR of AA19000 annealed conditions

Orientation relative to rolling direction	AA 19000 at annealed condition R	nR	$\bar{R}$	ΔR
0°	0.334	0.094	-0.156	0.396
45°	0.474	0.121		
90°	0.303	0.110		
Average	0.370	0.108		

Table 8: Plastic anisotropy ratio $\bar{R}$ and ΔR of AA5052 un-annealed conditions

Orientation relative to rolling direction	AA 5052 at un-annealed condition R	nR	$\bar{R}$	ΔR
0°	0.362	0.109	-0.246	0.373
45°	0.434	0.114		
90°	0.260	0.046		
Average	0.352	0.100		

Table 9: Plastic anisotropy ratio $\bar{R}$ and ΔR of AA5052 annealed conditions

Orientation relative to rolling direction	AA5052 at annealed condition R	nR	$\bar{R}$	ΔR
0°	0.260	0.090	0.857	0.640
45°	0.283	0.110		
90°	0.200	0.042		
Average	0.248	0.081		

4. Finite element modeling in ABAQUS

The ABAQUS/CAE is advanced nonlinear explicit analysis software which is used for analyzing models with non-linearity of parts in contact, material nonlinearity and geometric nonlinearity [15] [17]. The punch and sheet metal is modelled in ABAQUS software for punch of 200mm length, 100mm diameter made of steel and sheet of 220mm x 220mm x 1mm dimension for both AA19000 and AA5052. The punch and sheet are meshed with element size 9mm and 4.5mm respectively. The finite element model is shown in Fig. 9. The entire model is meshed with Quad shell -S4R (4 noded linear quadrilateral) element and the model is simulated with surface to surface contact parameters, force and structural output requests like displacement, stress and strain.

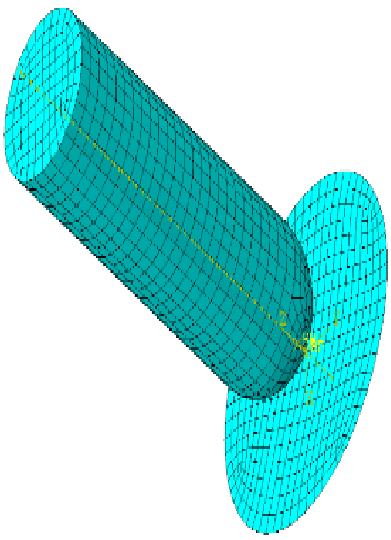

Fig. 9: Finite element model with shell elements

4. 1. AA19000 - annealed material

Fig. 10 shows the deformation occurring in AA19000 which is subjected to 100 kN. The material is subjected to load till the maximum deformation of 260.20mm is attained. Beyond this strain level, the material shell undergoes tearing and leads to failure of the formed sheet. The max. vonmises stress value of 56.232 MPa occurs at element 405 as shown in Fig. 11.

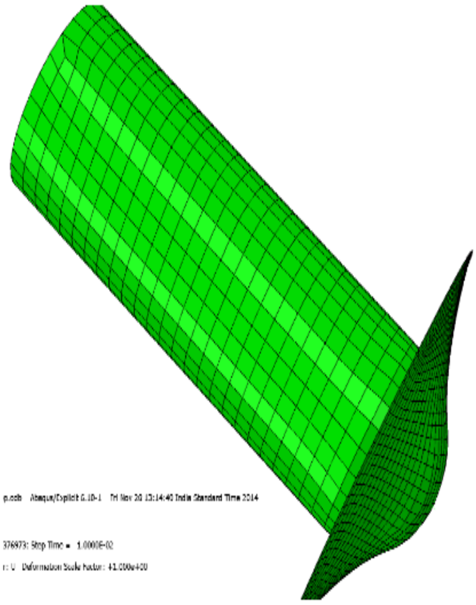

Fig. 10: Displacement plot for AA19000 (mm)

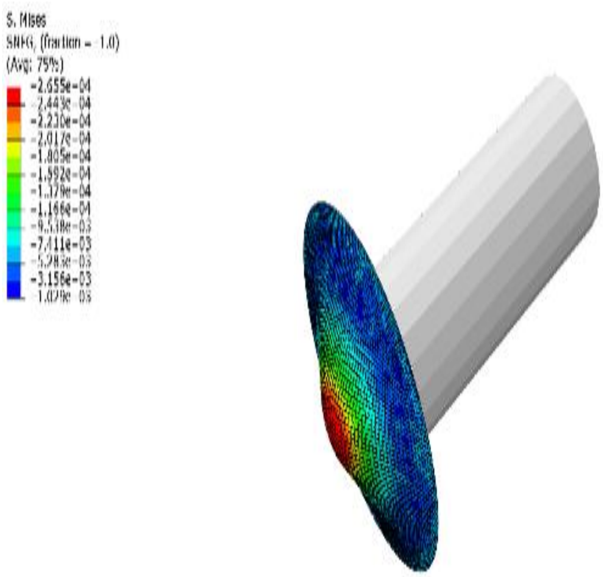

Fig. 11: Vonmises Stress plot for AA19000 (MPa)

4.2. AA5052 - annealed material

Figs. 12 and 13 show the deformation and stress distribution occurring in AA5052 which is subjected to 100 kN. The AA5052 model shows a displacement of 409.67 mm in z-axis. The displacement is considerably more for AA5052 sheet metal than AA19000. After simulating AA19000 and AA5052 sheet metal with values obtained from tensile test in ABAQUS/CAE, AA5052 sheet metal showed more displacement than AA19000 sheet metal. This indicates that the AA5052 has good formability.

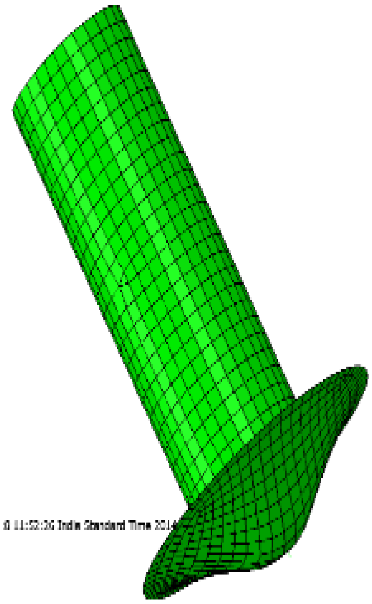

Fig. 12: Displacement plot for AA5052 (mm)

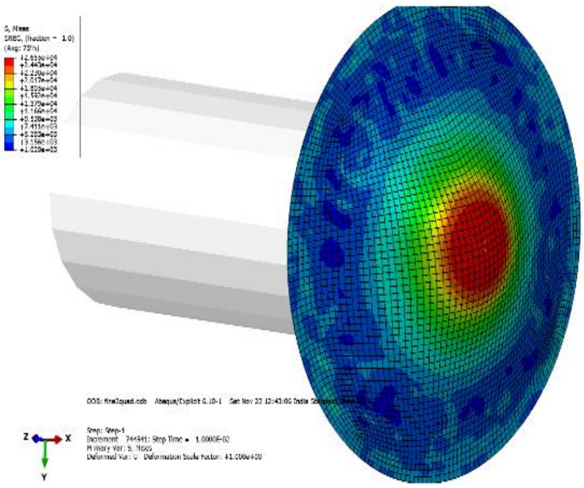

Fig. 13: Vonmises stress contour for AA5052 (146.916 MPa)

5. Conclusion

Formability of AA5052 and AA19000 aluminium alloy was investigated by performing tensile test and Erichsen cupping test at un-annealed and annealed conditions. Material properties like Young's modulus E, yield stress σ_y, elongation and ultimate strength σ_u were determined using the stress versus strain graphs. It was found that the material properties of the two aluminium alloys improved after annealing at 350°C for 15mins in furnace and followed by cooling inside furnace at room temperature. The experimental results indicate that both AA5052 and AA19000 have good formability but AA5052 exhibits better formability properties than AA19000. This enhanced formability properties are due to the presence of higher magnesium content. Hence AA5052 finds vast applications in automobile industry. On relieving the internal stress after annealing at 350°C, the material showed improvement in forming properties. The experiment results conformed to ABACUS/CAE simulations and thus the experimental results were validated.

REFERENCES:

[1] S. Toros, F. Ozturk and I. Kacar. 2008. Review of warm forming of aluminium - Magnesium alloys, *J. Materials Processing Tech.*, 207, 1-12. https://doi.org/10.1016/j.jmatprotec.2008.03.057.

[2] K. Siegert and S. Wagner. 1994. Institut für Umformtechnik, Universität Stuttgart, formability characteristics of aluminium sheet, *Training in Aluminium Application Tech., TALAT Lecture 3701*, 29.

[3] M. Janbakhsh, M. Riahi and F. Djavanroodi. 2012. Anisotropy induced biaxial stress-strain relationships in aluminium alloys, *Int. J. Advanced Design and Manufacturing Tech.*, 5(3).

[4] Z. Marciniak, J.L. Duncan and S.J. Hu. 2006. *Mechanics of Sheet Metal Forming*, Butterworth-Heinemann Publications.

[5] K. Logesh, V.K. Bupesh Raja and R.Velu. 2015. Experimental investigation for characterization of formability of epoxy based fiber metal laminates using Erichsen cupping test method, *Indian J. Sci. and Tech.*, 8(33). https://doi.org/10.17485/ijst/2015/v8i33/72244.

[6] Z. Marciniak, K. Kuczynski and T. Pokora. 1973. Influence of the plastic properties of a material on the forming limit diagram for sheet metal in tension, *Int. J. Mech. Sci.*, 15, 789-805. https://doi.org/10.1016/0020-7403(73)90068-4.

[7] G.E. Dieter. 1986. *Mechanical Metallurgy*, Mc Graw Hill, London.

[8] Y.C. Liu and L.K. Johnson. 1958. Hill's plastic strain ratio of sheet metals, *Metal. Trans. A*, 16, 1531-1535. https://doi.org/10.1007/BF02658687.

[9] G.E. Totten and D.S. Mackenzie. 2003. *Handbook of Aluminum: Physical metallurgy and Processes*, Volume 1, CRC Press.

[10] S. Aleksandrović, M. Stefanović, D. Adamović and V. Lazić. 2009. Variation of normal anisotropy ratio "r" during plastic forming, *J. Mech. Engg.*, 55(6), 392-399.

[11] O. Engler and V. Randle. 2010. *Introduction to Texture Analysis: Macrotexture, Microtexture, and Orientation Mapping*, 2nd Edition, CRC Press.

[12] K. Logesh and V.K.B. Raja. 2014. Investigation of mechanical properties of AA8011/PP/AA1100 sandwich materials, *Int. J. Chem. Tech. Research*, 6(3), 1749-1752.

[13] W. Xin-yun, H.E. Hu and X. Ju-chen. 2009. Effect of deformation condition on plastic anisotropy of as-rolled 7050 aluminum alloy plate, *Mater. Sci. and Engg.: A*, 515(1), 1-9. https://doi.org/10.1016/j.msea.2009.03.061.

[14] R. Esmaeilizadeh, K. Khalili1, B.Mh. Sadeghi and H. Arabi. 2014. Simulated and experimental investigation of stretch sheet forming of commercial aluminum alloy AA1200, *Trans. Non Ferrous Metals Society of China*, 24. https://doi.org/10.1016/s1003-6326(14)63086-7.

[15] Y. Li, M. Luo, J. Gerlach and T. Wierzbicki. 2010. Prediction of shear-induced fracture in sheet metal forming, *J. Mater. Process. Tech.*, 210, 1858-1869. https://doi.org/10.1016/j.jmatprotec.2010.06.021.

[16] K. Logesh, V.K.B. Raja. 2015. Formability analysis for enhancing forming parameters in AA8011/PP/AA1100 sandwich materials, *Int. J. Adv. Manuf. Tech.*, 81(1-4).

[17] G.M. Goodwin. 1968. Applications of strain analysis to sheet metal forming problems, *Metal. Ital.*, 60, 767-771.