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Experimental and Simulation Investigation of Non-Isothermal Uniaxial and Biaxial Deep Drawing Tests for AL6061-T6 Sheet

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Abstract: The process of Deep Drawing plays a vital role in the Production process of different parts in various process environments. Aluminum alloy sheets are increasingly used in automotive and aerospace industries. However, the aluminum alloy sheets are usually formed at elevated temperatures due to low formability at room temperature. The warm deep drawing process of aluminum 6061-T6 sheets are numerically studied by non-isothermal experimentation and simulation. To study the formability of AL6061 material, both uniaxial and biaxial tests are performed. The drawn depth and stress, strain distributions obtained from non-isothermal experimentation agreed well with up to 6% variation of simulation results.
Keywords: deep drawing process, AL6061-T6 alloy, warm forming, and non-isothermal process.

I. INTRODUCTION

The investigations and development of lightweight materials are very important issue in automotive and aerospace industries. Sheet metal parts are utilized in different industrial applications such as automobile and truck bodies, aircraft, railway cars, farm and construction equipment, beverage cans, kitchen utensils, etc. sheet metal forming processes are generally divided into three major categories that are cutting, bending and drawing. The product weight can be effectively reduced using lightweight materials such as aluminum alloys, which has excellent mechanical properties such as young's modulus strain hardening(n), strain sensitivity(m), yield stress, ultimate tensile strength,ductility.

The cylindrical shaped blank of aluminum alloy, which limits deformation at room temperature. Therefore, the aluminum alloy shows limited formability at room temperature. In general, the formability of aluminum alloy is effectively improved by increasing temperatures. Most studies investigated the formability of aluminum alloy sheets with cylindrical cup deep drawing in isothermal conditions .Non-isothermal forming has been introduced in which only die and blank are under heating condition, keeping punch at room temperature .Several papers on the warm forming of aluminum alloy was significantly improved at temperatures up to 300˚C, but work under non-isothermal condition at specified temperature has rare studies. Several research papers conducted FE simulation for the warm forming of aluminum alloy sheets. Using non- isothermal conditions with DEFORM, MARC. Although, few papers have been published on the FE simulations and experimentations for the warm forming of aluminum alloy sheets using non-isothermal conditions.

Many researchers have experimented with the high strength low formability materials like aluminum or magnesium alloys to evaluate their forming characteristics. These materials nowadays replace the steel in automobile and electronic industries due to their excellent properties like lightweight, high specific strength. Takuda et al (2002), Wang and Lee (2006), Van Den Boogaard and Huétink (2006), Gavas and Izciler (2007), Palumbo and Tricarico (2007) are some of those who used aluminum or aluminum alloys in their research work. Magnesium or magnesium alloys are used as investigating materials by Shoichiro Yoshihara et al (2003), Qun- Feng Chang et al (2007) (i& ii), Lee et al (2007) (i& ii), Ren et al (2009), Heung-Kyu Kim and Woo-Jin Kim (2010), Aimei Zhang et al (2011), to name a few.

Non-isothermal experimentation in deep drawing for AA5XXX alloys was conducted by Kaya et al[1], observed that the temperature improvement improves the limiting drawing ratio. Shehata F et al [2] conducted both uniaxial and biaxial test to study the formability of the material. Observations reveal that the elongation which improves due to increase in magnesium content, increase in temperature, and decrease in strain rate depends on the m-value. In biaxial test, the material less sensitive to temperature and strain rate compare to uniaxial tension. [3]S.Toros studies show that though aluminum alloys are excellent high strength to weight ratio, there formability increases only at elevated temperature such as 200 to 300 rather than room temperature. Uniaxial and Nakajima tests were conducted by Zhu Chen, Gang Fang, [4] to study the formability of 6061-T6 sheets using the FLD curves which predict the failure generated while drawing the sheets. It can be seen that increase in temperature and decrease in forming speed will give better drawing. Jacqueline Noder, [5]This paper examines non-isothermal warm forming experiments on AA7xxx-series channel sections at two different initial blank temperatures (187 and 253°C) with room temperature tooling.. Based on attached thermocouples during forming, thickness measurements and recorded force-stroke curves, the simulation model is validated. Kim, H. S, [6] this study examines the application of warm forming of aluminum alloys for automotive panels. Warm forming improved not only the deep-drawing formability of aluminum alloys but also their shape fix ability in hat-shaped bending. With increasing BHF, the shape fix ability improved further and was comparable to that of Steel. Finch, D. M., Wilson [7] studies shows interest in tailored welded blanks for weight reduction which is as challenging task in formability. The experiments performed above re crystallization temperature on 6061 and 7075 blanks using damage factor damage factor based on Cockcroft Latham algorithm was taken as the constraint for defect free product. Li, D., and Ghosh, A [8] Uniaxial tensile deformation behavior of three aluminum sheet alloys, Al 5182_ 1% Mn, Al 5754 and Al 6111-T4, are studied in the warm forming temperature range of 200_ 350 8C and in the strain rate range of 0.015_ 1.5 s_1. The enhancement of strain rate sensitivity (m value) with increasing temperature accounts for the ductility improvement at elevated temperatures. The uniaxial tensile test is identified to serve as a screening test for ranking relative formability among different sheet alloys. Based on this criterion, the strain hardened 5xxx alloys (Al 5182_ Mn and Al 5754) have shown better formability's than the precipitation hardened alloy (Al 6111-T4).

In this study, the warm deep drawing processing under non-isothermal condition for aluminum alloy sheets has been studied experimentally and numerically. In order to verify the warm forming process, tensile tests and warm cylindrical cup deep drawing experiments were conducted. The drawn depth and stress, strain distributions of the sheet obtained in the experiments were compared with FE simulation results.

II. EXPERIMENTAL SETUP

A. Uniaxial Tensile Test

Understanding material mechanics is critical for engineering. The uniaxial tension tests provide a simple and effective way to characterize a material's response to loading. By subjecting a sample to a controlled tensile or compressive displacement along a single axis, the change in dimensions and resulting load can be recorded to calculate a stress-strain profile. From the obtained curve, elastic and plastic material properties can then be determined. Therefore, to investigate material mechanics and gain experience in uniaxial testing, we performed compressive and tensile tests on alloys, pure metals, and calculated their Young's modulus, yield stress, ultimate tensile strength, and strain hardening exponent, strain sensitivity, strength coefficient.

The Engineering and True Stress strain behavior of the aluminum sheet at elevated temperatures indicated increased elongation and decreased stress. The uniaxial tensile machine specifications are as follows: load cell capacity of 100KN, Strain rate of 0.33/s with cross head speed, and each piece took 5 minutes to complete the experiment. The uniaxial tensile machine is fixed with furnace and down jaw is fixed, up jaw is movable. The maximum furnace capacity is 1200˚C. The uniaxial tensile machine heaters are prepared by using silicon carbide materials, to avoided heat exposure to load cells, asbestos cloths are used and load cells are surrounded with water cooling circulation. The uniaxial tension machine as shown in Fig1.

Fig: 1 uniaxial tension machine.

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For uniaxial tests, the displacement is typically held at a constant rate, and displacement and resulting load are recorded. The load is measured by a series of strain gages, or “load cell,” while the displacement can be recorded as displacement of the crosshead, or the beam on which the specimen load frame is mounted. For more precise load measurements, strain gages or an extensometer can be directly fixed to the specimen. To make direct comparisons between materials, loading responses must be normalized against sample geometry. Therefore, the dimensions of each sample are noted to compute stress and strain from load and displacement, respectively. In tensile tests, specimens typically have two shoulders and a gauge section in between, the Sample to be created for the tensile test with dimensions, as shown in figure.2

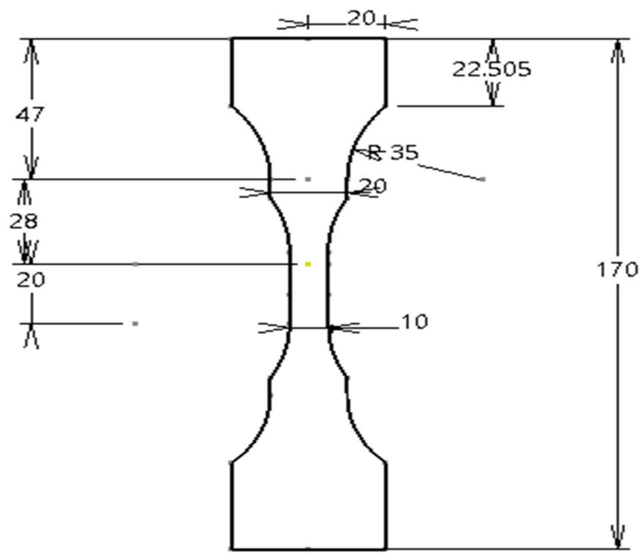

Fig.2.Sample to be created for the Tensile test.

Table .1
Mechanical Properties OF AL6061-T6

1	Density	2.7 g/cc
2	Youngs modulus	68.9 GPa
3	Poisson’s ratio	0.33
4	Tensile Yield stress	276 MPa
5	Ultimate tensile strength	310 MPa
6	Shear Strength	207 MPa

For this section of the laboratory experiment, a metal and three metal alloys aluminum 6061 were subjected to uniaxial tension using the ADMT-UTM (USA) tension test specimen model. The samples standards ASTMB 557 structures to localize the point of failure to the centre of the samples during testing the initial sample dimensions (width and thickness) were measured, and then the samples were mounted into the fixed lower base of the ADMT-UTM (UASA) tension test specimen model. The gage length L between the fixed lower base and upper fixture was measured to determine the initial length of the sample undergoing uniaxial tension.

To determine the mechanical properties, uniaxial tensile tests on AL6061 were conducted at temperatures ranging from room temperature to 300^{o}C. AA6061-T6 aluminum alloy sheet specimens with a thickness of 2mm were prepared according to ADMT-UTM (USA) tension test specimen model.

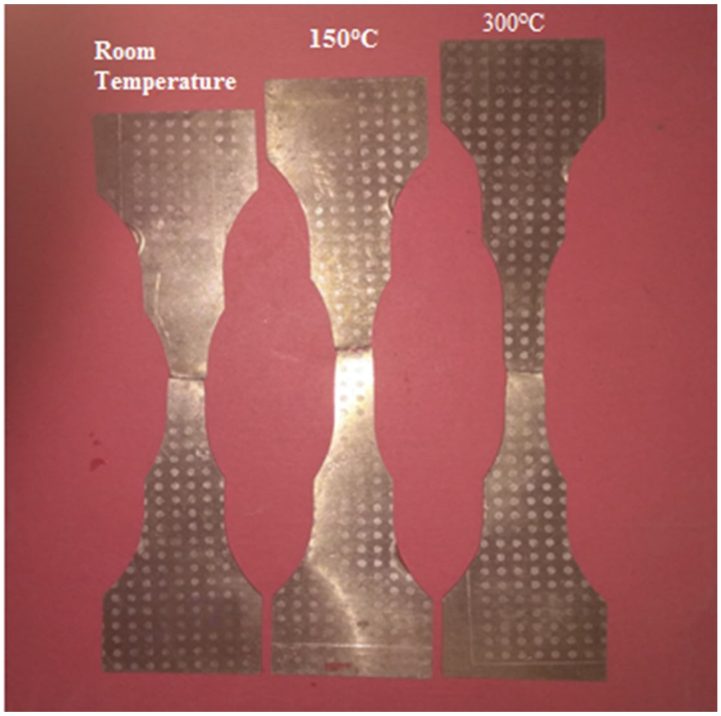

Fig.3.Aluminium 6061-T6 (2mm) specimens for tensile testing at elevated temperatures.

Figure 3 shows the aluminum 6061-T6 with 2mm thickness specimens for tensile testing. Tensile specimen with specified dimensions which are shown in the above Fig.2 had a gauge length of 170 mm and width of 40 mm. The specimens were elongated at nominal strain rates of 0.33/s. The true stress-strain behavior of the AL6061 sheet at elevated temperatures indicated increased elongation and decreased stress. The stress strain relations of the aluminum at 32^{o}C to 300^{o}C along the rolling direction. The specified chemical composition of these sheets is shown in Table 2.

Table .2
Chemical Composition OF Al 6061-T6

Component	Wt. %	Component	Wt. %	Component	Wt. %
Al	95.8 - 98.6	Mg	0.8 - 1.2	Si	0.4 - 0.8
Cr	0.04 - 0.35	Mn	Max 0.15	Ti	Max 0.15
Cu	0.15 - 0.4	Other, each	Max 0.05	Zn	Max 0.25
Fe	Max 0.7	Other, total	Max 0.15		

B. Biaxial Cup Deep Drawing

In the deep drawing technique, the flat piece obtained from a large sheet metal is named blank which is usually clamped on the top surface of the forming die by means of a rigid tool conventionally called blank-holder. In order to obtain a symmetric shape for a defects- free product, the centre point of the blank should coincide exactly with the centre of the die opening. Blank holder to catch the blank, punch force to form the blank into the die cavity, are the two main resources contribute in providing the force needed to form the sheet metal blank completely.

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The load capacity of machine is 13 Tones and maximum pressure is 115 bars. The stroke of main ram is 300mm and height of machine is 1500 mm. The formability of the AL6061-T6 sheets under deep drawing tests are conducted by using 13-ton hydraulic press at temperature ranging from room temperature to 300̊ C. as shown in Fig.4.To increase the blank temperature, the blank is heated inside the preheated tool. In non-isothermal process, blank and die are heated, while punch is maintained at room temperature. The blanks are heated to the forming temperature using muffle furnace box. The main tool dimensions are as follows: punch diameter of 49.8mm, blank thickness of 2mm, die diameters for 2mm blank thickness, using 52.5/52.6mm, blank diameter of 105mm, and die travelling distance is 152mm, die profile radius 15mm. the blank holding force varied from 3 to 6 KN, Die force 67.1 KN and boric acid paste is used as a lubricant. The experiment is conducted on cylindrical blanks with Hydraulic Machine shown in above Fig.4

Fig: 4 deep drawing experimental machine.

III. EXPERIMENTAL PROCEDURE

A. Uniaxial Tensile Test

In order to investigate the effects of temperature on the mechanical properties and forming behavior of the aluminum alloy, the tensile test was performed on 2mm AL6061-T6 sheet at room temperature, 150˚C and 300˚C. The specimens were elongated at nominal strain rates of 0.33/s. The Hollomon's constitutive equation is applied to analyze the material properties

$$\sigma T = K€^{n}$$

Where, σT = true stress, €= true strain, n= strain hardening and k= strength coefficient.

The stress–strain data were recorded and the mechanical properties yield strength (YS), ultimate tensile strength (UTS) and total percentage elongation were determined. In the warm working temperature range, flow stress of the alloy is influenced by both strain and strain rate. In case of most of the common alloys, the flow stress equation which incorporates the effect of strain hardening and strain rate hardening is given by

$$\sigma = K €^{n} €^{.m}$$

From the above mentioned equation strain hardening, strength co-efficient, strain rate sensitivity were evaluated. The determined coefficients were used as input in FE simulations to define the flow curve of the material in the warm working temperature range.

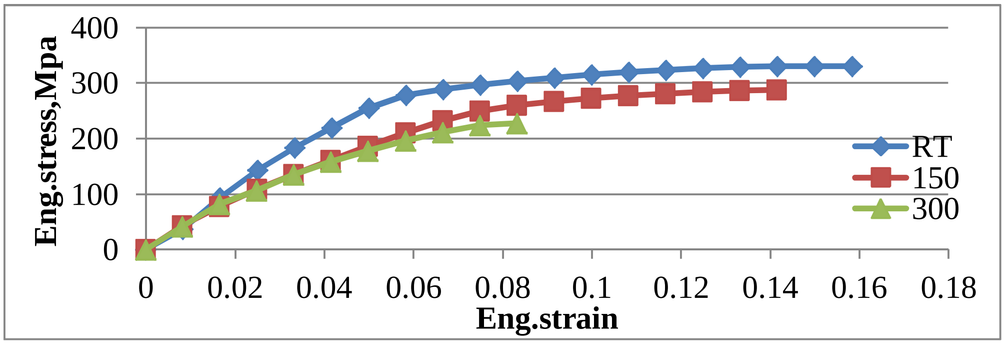

Fig: 5 The Eng. stress strain relationship of AL6061-T6 at elevated temperatures.

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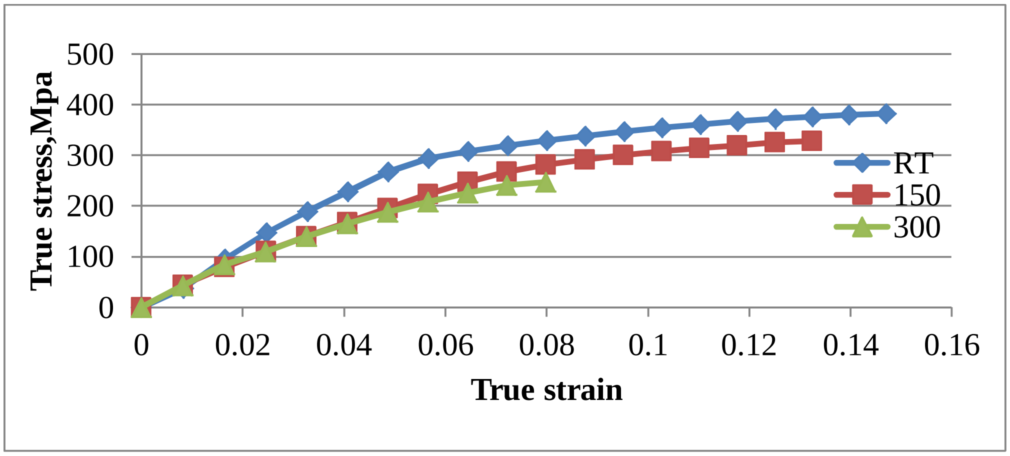

Fig: 6The True stress-strain curves of aluminum alloy at elevated temperatures.

The engineering and true stress-strain relationships obtained from the tensile tests at the three different directions of the AL6061-T6 sheets of 2mm in thickness used in this work are presented in Figure 5and Figure 6 respectively. Also, the mechanical properties acquired from these tests are listed in Table 3

Table 3
Calculated results of Aluminum 6061-T6 (2mm thick) samples for material properties of tensile testing specimen at Elevated temperatures.

TEMPRATURE	E	σy	UTS	DUCTILITY	n	K(Map)	m
RT	5195.274	299	331	9.03%	0.2778	665	0.015
150˚	3524.967	250	288	10.25%	0.1803	465	0.033
300˚	3341	165	228	11.9%	0.0875	303	0.088

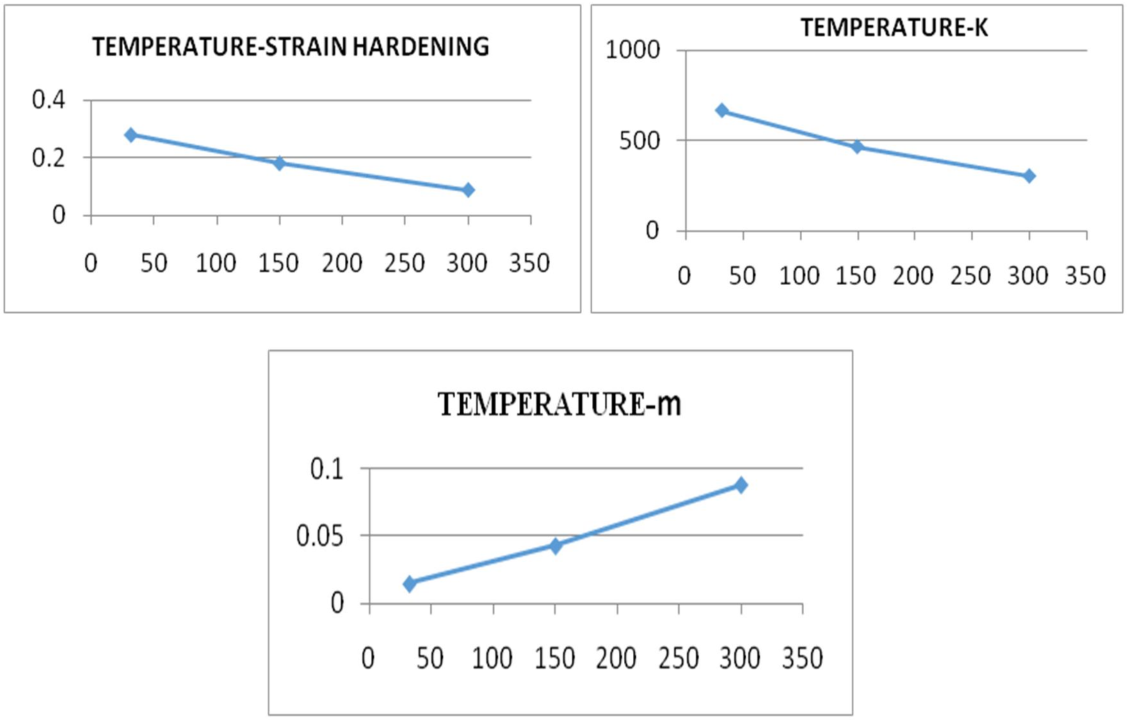

Fig 7: The results of the tensile testing of the AA6061-T6 sheets with different Temperatures- strain hardening, strength coefficient, strain sensitivity.

Tensile properties of AA6061-T6 sheets YS, UTS and total percentage elongation are determined from the stress–strain data at these conditions and these are summarized in Table 3. For a given strain rate, with an increase in the temperature, strength (both YS and UTS) decreased and ductility increased. Similarly, at a given temperature, as the strain rate increased, YS and UTS increased and ductility decreased. In this temperature range of testing, though softening is responsible for decrease in flow stress with temperature, strain hardening is also significant at 32˚C and 150˚C as indicated by increase in flow stress with strain. However, at 300˚C, strain hardening is lower and is almost negligible at the lowest strain rate. This is consistent with the decrease in n value with an increase in the temperature. Effect of strain rate is clearly visible on the flow stress, and it became more pronounced as the temperature increased. This is in accordance with an increase in the strain rate sensitivity index (m) with temperature. Higher m value also helps in achieving higher total elongations. The alloy exhibited more than 10% total elongation at 32˚C to300˚C and the maximum elongation of 11.9% has been obtained at the highest temperature and the lowest strain rate. The tensile properties and stress–strain data clearly indicate that both strain and strain rate have a strong influence on the flow stress in this temperature range. Hence, to define the flow curves of this alloy in FE simulations, it is important to use the constitutive equation which incorporates the effect of strain and strain rate on flow stress. The experimental true stress–true strain data at different strain rates and temperatures were used to fit a strain rate–dependent power hardening rule and the material coefficients were determined at each temperature. The values of strain hardening exponent (n), strain rate sensitivity index (m) and strength coefficient (k) in the constitutive equation with temperature are given in Table 3. The engineering and true stress– true strain curves predicted with the developed constitutive equations agreed well with the experimental curves as shown in Figures5 and 6.

Figures6 and Table 3 show that both stress and strain characteristics of the specimens change with different temperatures. However, the dependency of the strain characteristics is stronger than that of rolling direction the stress characteristics. While the differences between the minimum and maximum values of the yield and tensile strengths of their average values, the difference between the minimum and maximum values of the strain at maximum stress and ultimate strain of their average values .It should be noted that the differences between the sheets with different temperatures are not all systematic differences and, for example, the batch scatter of the properties also plays a role. For AL6061-T6, the strain at maximum stress and ultimate strain increased as sheet temperature increased the strain at maximum stress again slightly decreases while the ultimate strain slightly increases. However, one can therefore conclude that temperatures increased from up to 300˚C, the strain limits of the specimens increase.

B. Biaxial cup Deep Drawing Test

The drawing operation begins when the punch moves down, pushing the blank into the die cavity. Through the operation, the blank experiences a complex sequence of stresses and strains continuously as it is formed into the required shape. The drawing process involves different forming stages, shown in Figure 8a. At the beginning, the forming force is transmitted to the blank through the die, resulting in a bending action in the metal over the punch and die corners. In this stage the metal is drawn slightly towards the opening of the forming die to produce an initial shallow cup as shown in Figure 8b. As the die is kept moving downwards, the metal bent previously just over the around corner of the punch is drawn into the clearance between the punch and the die, where it must be straightened to form the side wall of the final cup. At the same time, the bottom of the initial cup and the metal that was bent over the die corner move downwards correspondingly with the punch. In order to keep the metal at the die corner not stretched excessively at this stage more metal must be sent from the flange portion. Consequently, the outer portion of the blank is drawn continuously towards the die cavity to compensate the metal being used in forming the side wall, resulting in reducing perimeter diameter of the blank

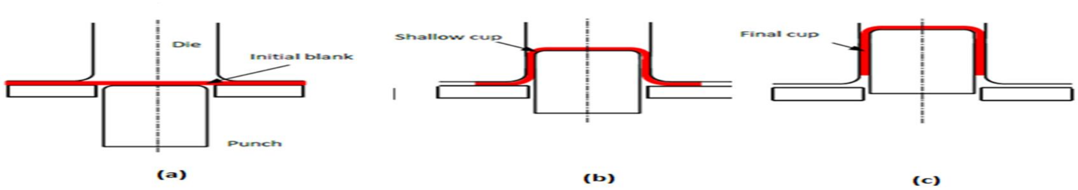

Fig.8.Steps of Deep Drawing Process

Experiments were performed with a tool set schematically presented in Figure 8. The blanks were placed on top of cold punch which was slightly extended vertically from the blank holder .The blanks were lubricated with a water-based paste. The paste was applied on both sides of the blank before being placed on top of the punch. For drawing at warm temperature, the die and the blank holder were

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Fig: 9. Experimental Setup used for warm deep drawing.

Heated with internal heating blank and the punch were cooled with water through internal water circulating channels. Thermocouples were used to measure the temperatures of punch and the die. During the heating process, water of the lubricant evaporates leaving the lubricant on the blank, which still gave sufficient lubrication at 300˚C. The blank was heated up and reached the desired temperature soon after it came into contact with the die and blank holder. This is referred to as holding shown in Figure 8a. Drawing was performed by moving down the blank holder and the die, and the punch remained immobile as shown in Figure 8b. During drawing operation, the force exerted by the punch was recorded against the punch displacement. It was stopped when the desired depth was reached. The cups were water quenched after the drawing. For drawing at room temperature the sequence of operation remained exactly the same except the heating and cooling steps.

It is clear now that the flange region and the side wall of the cup significantly experience the great portion of the deformation through drawing processes. In the flange region, the friction forces play a crucial role in the success of the drawing operation. Once the drawing force is applied to the flange portion conquers the friction between the blank and the surfaces of the blank holder and the die, and then the material starts moving towards the forming cavity by using sectional positions for warm deep drawing, as shown in Fig.10.

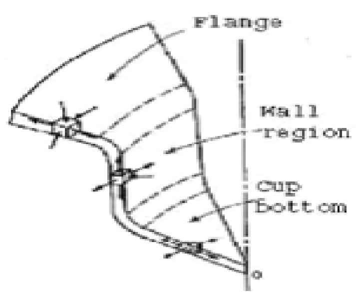

Fig.10.Sectional positions of warm cylindrical cup deep drawing.

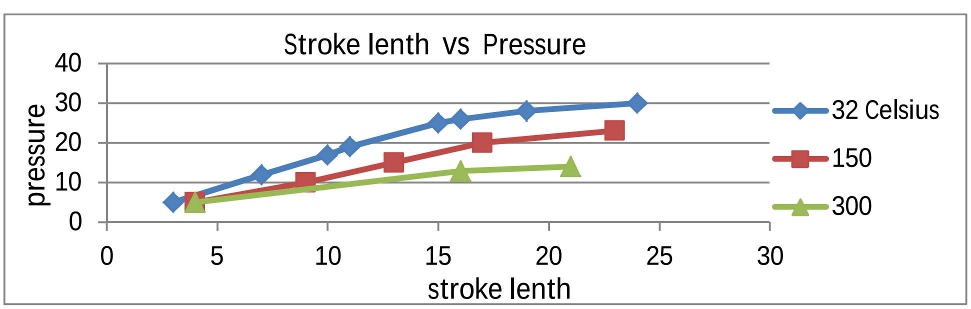

Fig.11.Stroke length vs Pressure.

This is the variation graph which shows stroke length vs pressure at 32˚C, 150˚C, 300˚C and the appropriate values shows how the increase in temperature gives better formability.

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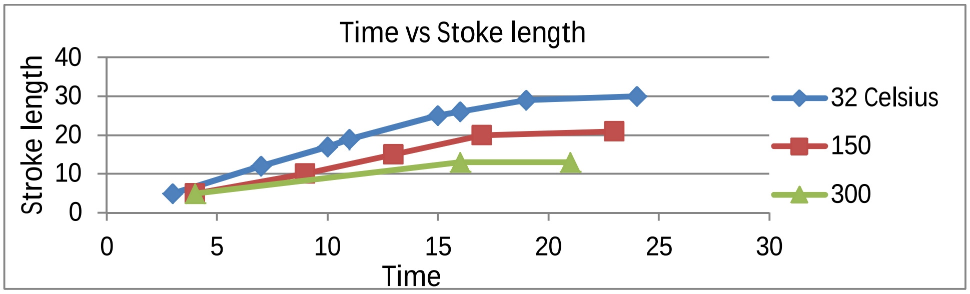

Fig.12: - Time vs. Stroke length.

This is the variation graph which shows time vs stroke length at 32˚C, 150˚C, 300˚C.

Table.4. Experimental values

Condition	Height(mm)	Thickness(T1,T2, T3,T4,T5)	Volumetric Stresses(MPa)			Specimens
			σ1	σ2	σ3	
32˚C	16	1, 0.95, 0.92, 0.87 0.96	2500.38, 11557.97,14084.53,5741.23,61.52	10197.88,1362.84,6442.15,28521.84,14688.10	6021.86,5486.50,5159.23,15638.02,7396.41	
150˚C	18	0.99, 0.96, 0.94, 0.85, 0.95	2129.01,3061.91,536.73,9490.97,9121.67	4560.49,17922.95,4843.67,589.09,1508.22	895.01,7552.12,4045.11,11127.05,3982.42	
300°C	24	1, 0.97, 0.94, 0.91, 0.90	4424.75,2345.69,2259.06, 3758.7,2771.84	4922.21,10631.27,11952.08, 2399.35,2359.82	942.55,-6782.51,-6637.13,11346.45,435.48	

T1= FLANGE, T2= DIE CORNER, T3= WALL, T4= PUNCH CORNER, T5= BASE

IV. SIMULATION

A. Simulation of Uniaxial Tensile Test

The tensile test simulation is performed in ANSYS19.2 software; In Figures below shows the simulation of work piece model and deformations at elevated temperatures. The reference temperature for the three required temperature simulation is taken as 20˚C and geometric properties are given according to dimensions. Meshing is done in size controls, one end of the tensile work piece is constrained and other side a gradual stepped load of 30KN is applied and solved. The results are noted as follows.

The figure 13 shows 3D model of the tensile test specimen. The initial condition of the sample at the time of the application of the load. The Fig14 shows Thermal conductivity Specimen at elevated temperatures. The final condition of the sample, i.e. the sample is broken into two pieces and the values of von misses stress that has obtained during the test.

By conducting the tensile test, we obtained the stress-strain graph. The plotted graphs are shown in above Fig 5 and 6. Elastic deformation occurs in the initial portion of a stress-strain curve, where the stress-strain relationship is initially linear as shown in above fig 6. In this region, the stress is proportional to strain. Mechanical behavior in this region of stress-strain curve is defined by a basic physical property called the modulus of elasticity. The modulus of elasticity is the slope of the stress-strain line in this linear region, and it is a basic physical property of all materials. It essentially represents the spring constant of a material. The modulus of elasticity is also called Hooke's modulus or Young's modulus.

The proportional limit is a point in the elastic region where the linear relationship between stress and strain begins to break down. At some point in the stress-strain curve, linearity ceases, and small increase in stress causes a proportionally larger increase in strain. This point is referred to as the proportional limit because up to this point, the stress and strain are proportional. If an applied force

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below the PL point is removed, the trace of the stress and strain points returns along the original line. If the force is reapplied, the trace of the stress and strain points increases along the original line.

The elastic limit is a very important property when performing a tension test. If the applied stresses are below the elastic limit, then the test can be stopped, the test piece unloaded, and the test restarted without damaging the test piece or adversely affecting the test results. For example, if it is observed that the extensometer is not recording, the force-elongation curve shows an increasing force, but no elongation. If the force has not exceeded the elastic limit, the test piece can be unloaded, adjustments made, and the test restarted without affecting the results of the test. However, if the test piece has been stressed above the EL, plastic deformation will have occurred, and there will be a permanent change in the stress-strain behavior of the test piece in subsequent tension tests.

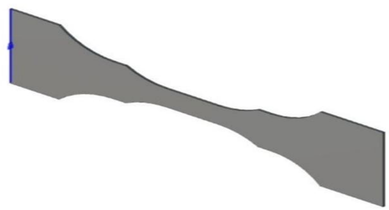


Fig.13.3D model of the tensile test specimen.

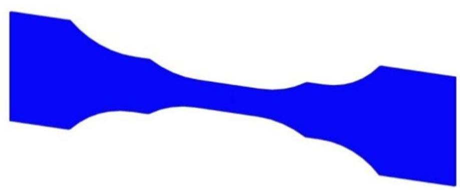
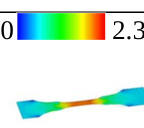
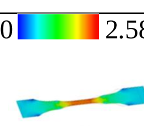
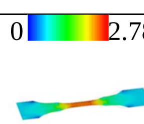


Fig.14.Thermal conductivity Specimen at elevated temperatures.

Table.5. Simulation values for tensile specimens.

Temperatures	Deformation	Vonmises stress(MPa)	Principle stress(MPa)	specimens
32˚C	2.341	179	176	0 2.341 
150˚C	2.585	211	206	0 2.585 
300˚C	2.78	251	234	0 2.78 

The Tensile Test Analysis of AL6061-T6 using finite element method has been conducted using a computer
Program called ANSYS 19.2. The results have been obtained. From the stress-strain graph it is understood that
The Aluminum alloy follows the Hooke's Law i.e., stress is directly proportional to strain. After the linear region in the graph, there occurs necking on the sample and finally it breaks.

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B. Simulation of Biaxial cup deep Drawing

Non-isothermal simulation of cylindrical cup deep drawing of the aluminum alloy 6061 at elevated temperatures is performed using ANSYS 19.2 software. Commonly half of the geometries are modeled due to their symmetric boundary condition and meshed model as shown in Figures14 and 15. Tools are treated as rigid bodies with Non- isothermal and mechanical properties. The material properties of the AL-6061T6 Sheet obtained from the tensile test were used in simulation. The simulation parameters are as follows: punch velocity of 1mm/s, associated thermal conductivity of 32˚C to 300˚C, die travelling timing steps, and pressure in MPa, and punch strokes are depending on the applied pressures as per experimental procedure, the variations of the symmetrical cups at elevated temperatures and simulation values of the biaxial cups as shown below Table.6

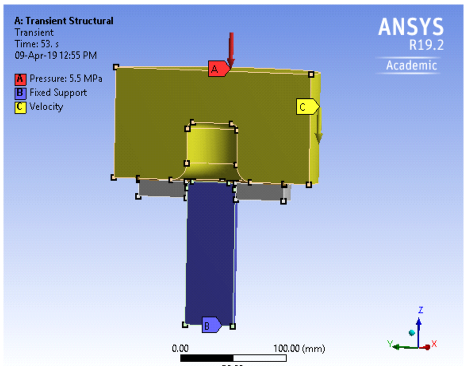


Fig.14.Symmetric boundary.

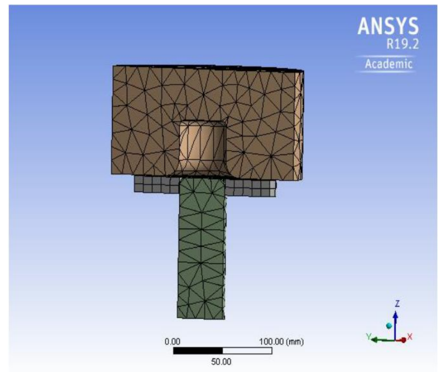
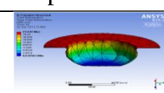
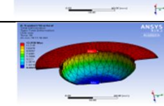
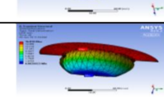


Fig.15. Simulation of meshed model.

Table.6.Simulation values for biaxial cups.

Temperatures	Deformation	Stresses(MPa)	Specimens
32˚C	15.96	5755.23,28524.88,15629.03	
150˚C	17.85	9491.99,588.1,11122.35	
300˚C	23.96	3758.9,23996.36,11346.5	

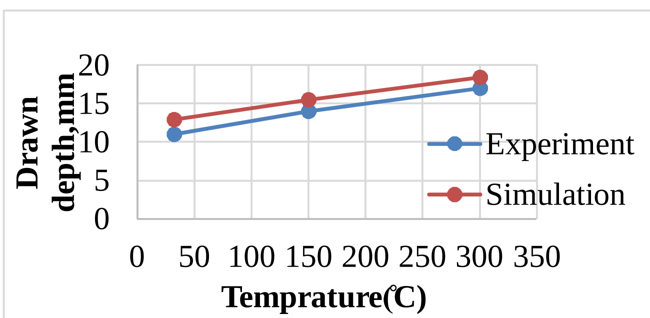


Fig: 16. Experimental and simulation relationships between forming temperature and drawn depth.

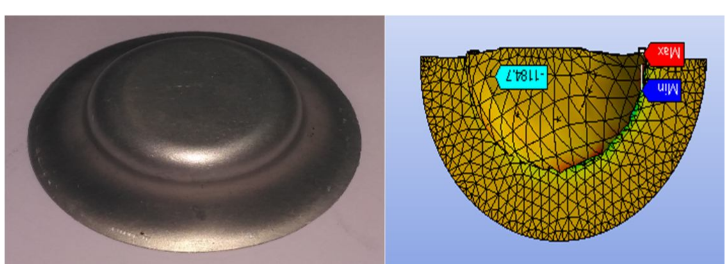


Fig: 17. Experimental and Simulation drawn shape of the cylindrical cup at 300˚C.

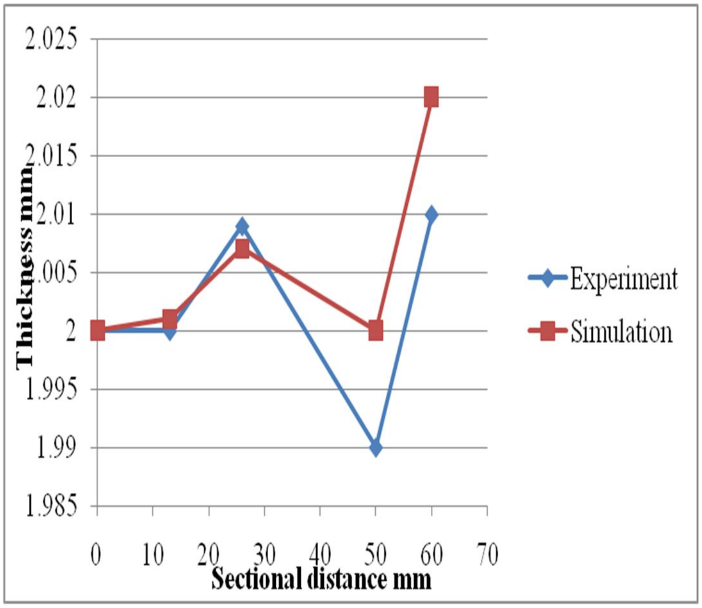


Fig.18. Comparison of Experimental and Simulation thickness distribution at 300˚C.

The simulation drawn shape of cylindrical-cup deep drawing is shown in Fig.16, Which indicates that the drawn depth increases with increasing temperature for both the simulation and experiment. The cylindrical blank, indicates the non-isothermal condition simulation results using a flow stress curve at room temperature and 300˚C. The study assumed that the blank would be rupture when the tinning ratio exceeded at die corner position and flange positions of the cup.

There is a considerable discrepancy of the drawn depth at the non-isothermal condition simulation at tool temperature of 300˚C.the deformation of the non-isothermal simulation agrees with the drawn depth of the non-isothermal experimental. The cup wall is cooled and constant by the punch in the non- isothermal simulation. The blank can be more easily drawn from a high temperature that is 300˚C.

Figures 17 and 18 shows the drawn shapes and thickness distribution from the experiment and simulation at up to 300˚C, respectively. The simulation the thickness distribution agrees with the experimental results. The temperature was lower at the punch corner and increased towards die corner. A discrepancy between the experimental and simulation results was due to different grid sizes.

V. CONCLUSION

The evaluation of the formability of aluminum alloy sheet 6061-T6 was studied using both experimental approaches and simulation modeling. The tensile tests are indicated that the both engineering and true stress-strain curves decreased with increasing temperature. With a stress- strain of 300˚C, and the mechanical properties of the aluminum tensile work piece specimens are indicated that when temperature increases with the decreasing young's modulus. When E increases but yield stress or n decreases, similarly when E decreases but n or yield stress increases. The temperature increases with the ultimate tensile stress will be decreases, as well as ductility increases with also increasing the strain rate sensitivity with respect to temperatures. The temperature is an increase with strength coefficient is decreases. The warm cylindrical-cup deep drawing indicated that the cup height increased with increasing temperatures. The better formability is obtained from non-isothermal simulation agreed with the experimentation results. And finally we will conclude that the better formability of cylindrical cup will be agreed with higher temperature of 300˚C, in this experimentation and simulation results. Future work will focus on determining the process conditions of warm deep drawing, such as die corner radius, spring back effects, using non-isothermal simulations. Further work can be extended to analyses different thickness plates at different speeds, pressures and temperatures. This project extended to bending and crushing analysis for experimental results to validate the manual and simulation results.

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