

## **FORMING OF HIGH STRENGTH / LOW FORMABILITY METAL SHEETS AT ELEVATED TEMPERATURES**

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**Abstract-** The purpose of this study is to determine the limits and to investigate the efficiency of sheet metal forming process at elevated ( warm / hot ) temperatures. Deep drawing of HSLA / UHSLA steels, aluminium, titanium and magnesium alloys in an effective way is possible only at elevated temperatures and has some indefinitenesses. In the study, deep drawing simulations are realized with a titanium copper alloy and a low alloy steel to investigate the deep drawability of high strength / low formability metal sheets. The comparison of the results obtained from this study with the other experimental, analytical and computer aided studies found from the literature showed that the results are coherent. From the studies its understood that, the critical temperature that makes the deep drawability maximum differs from material to material. This temperature is a complex function of the material and deep drawing process parameters.

**Keywords-** Deep Drawing, Warm / Hot Forming, High Strength Metals, Finite Element Analysis.

### **1. INTRODUCTION**

Although the deep drawing process of high strength / low formability metals has an extensive industrial application area, deep drawing at room temperature has serious difficulties because of the large amount of deformations revealed and high flow stresses of the materials mentioned [1]. Thus; crumples, wrinkles and earings will occur on the product surface because of the anisotropy of the materials. Elevated temperatures decrease the flow stresses and increase the formabilities of the materials and thus deformations become easier. The effective basic mechanism in pressing is plastic deformation. Because of this, deformation temperature has to be determined by taking this point into consideration. The advantages of warm / hot sheet metal forming method are as follows.

- Metals can be formed which can not be formed at room temperature.
- By the way, manufacturing of light and high strength products becomes possible.
- Press forces decrease.
- The probability of defect formations on product surface decreases.

There are two different methods for heating process. In the conventional method, the material is heated in the oven and after the heating process it is transferred to the press environment. With this method, a homogeneous heating condition should be supplied, but heat loss will appear during material transport process. In the second method,



inner panels because of the better formability and 6xxx series for outer panels because of the surface quality. The “household” alloy 1050-H14 is used for comparing the deep drawabilities of 5xxx and 6xxx series alloys at elevated temperatures. Another study about warm deep drawing of aluminium sheets examines the finite element simulation of heat transfer during the manufacturing stage [5]. Similar studies are realized at this subject by Finch et al., Fukui, Lenz, Miyagawa and Tozawa. In these studies forming limits in cylindrical deep drawing are investigated in different temperature, forming geometry and lubrication conditions.

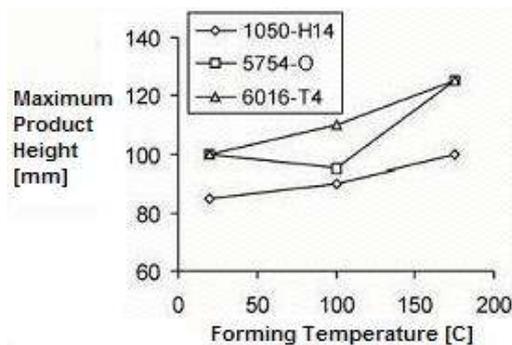


Figure 2. The effect of temperature on formability of aluminium [1].

Deep drawing at elevated temperatures has not yet become an industrial application and for this reason it has some indefinitenesses. Literature scope about forming at elevated temperatures is limited and not enough at the time. For this reason, determination of the parameters and the computer simulation of the manufacturing process are prior stages that have to be realized for further studies. When the literature about this subject is scanned it is seen that there are quite enough studies with aluminium and magnesium. But there are only a few studies with titanium and steel. There must be a lot more studies for the development and common applications of the process. The needed temperature for steel sheets is quite high and this situation should be the reason for the low number of studies about this material.

The aim of this study is to determine the parameters that are effective in this process and to examine the limits and appropriateness of the process with computer simulations by referencing to the preceding studies about this subject from literature. A validity research is done by comparing the results obtained from the analysis with the data belonging to former studies. In general, parameters that effect formability can be enumerated as follows: flow stress, maximum strength, total elongation, plastic deformation rate, direction dependent anisotropy, hardening parameter, strain rate, chemical composition, cold / hot rolling, thermomechanical material history. And at elevated temperatures strain rate sensitivity index must be added to the parameters mentioned above [6]. Some of the parameters mentioned above are temperature dependent and so have critical function at elevated temperatures. At this point, parameters of the deformation process at elevated temperatures can be summarized as follows:

1. *Temperature,*

2. *Temperature gradient,*
3. *Strain rate ( $v$ ),*
4. *Strain rate sensitivity index ( $m$ ),*
5. *Material history.*

By taking the basic process parameters which are stated above into consideration, it is understood that the modelling of warm / hot forming process comprises complex calculations and functions. In addition to this, there are a lot of factors depending on raw material's manufacturing method, geometry, pattern geometry and pattern properties that make foreseeing of the product properties before the manufacturing process difficult, especially in sheet metal forming. For example usually, cold forming processes that were made beforehand decrease the warm formability of aluminium alloys [7].

In the scope of this study; we mentioned the mechanical properties which influence forming of materials, critical parameters at elevated temperatures, in-process heating systems [8], results of the experimental and computer aided studies that are about warm / hot forming of titanium, aluminium and magnesium alloy sheets and finite element analysis procedures of the process. Afterwards geometrical and mechanical informations of the analysis which are made in this study are presented and the results of the analysis are discussed.

## 2. FINITE ELEMENT ANALYSIS

A product of MSC Software, commercial Superform 2002 packet program, is used for the computer simulations of warm / hot deep drawing process in this study. In the analysis, two dimensional axisymmetrical model is used since the process is axisymmetric. Analysis are realized in different temperatures to find the appropriate temperature by considering material properties. The appropriate ( critical ) temperature for forming is the temperature in which there is no decrease in product quality, there are no local strains and no Luders bands formation takes places. For this reason, the strain rates and temperature ranges in which Luders bands forms must be determined [2]. Anyway, one of the advantages of forming at elevated temperatures is, no Luders bands take place [1]. Because they form relatively at low temperatures. Temperature gradient is applied in some of the analysis to research the effects of this condition on forming. IMI 230 ( a titanium copper alloy ) and 20MnCr5 ( a low alloy steel ) are used as sheet workpieces. Chemical compositions of these materials are given in Table 1.

Table 1. Chemical compositions of the materials used in the analysis [9].

<b>IMI 230</b>	<b>Component</b>	Cu	Ti		
	<b>% Weight</b>	2.5	97.5		
<b>20MnCr5</b>	<b>Component</b>	C	Cr	Mn	Si(max)
	<b>% Weight</b>	0.19	1.15	1.25	0.40

Sheet metals which are chosen to be our workpieces are low alloyed materials with high strength. Cylindrical and spherical punches are used in the analysis. Punch and matrix are accepted to be rigid. Sheet thickness was 1 mm. Process model and geometry are given in Figure 3.

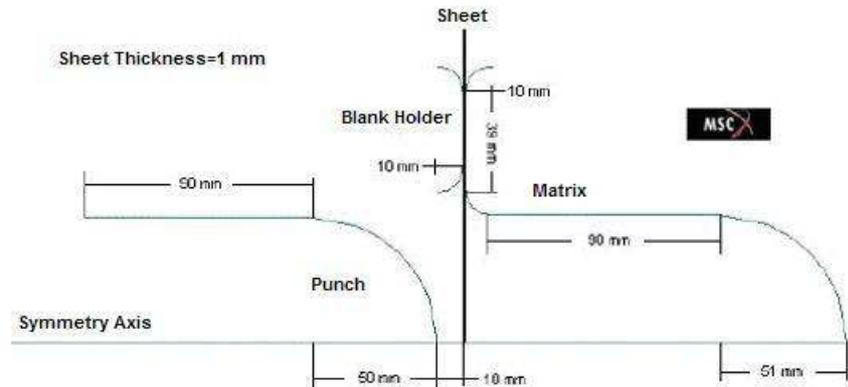
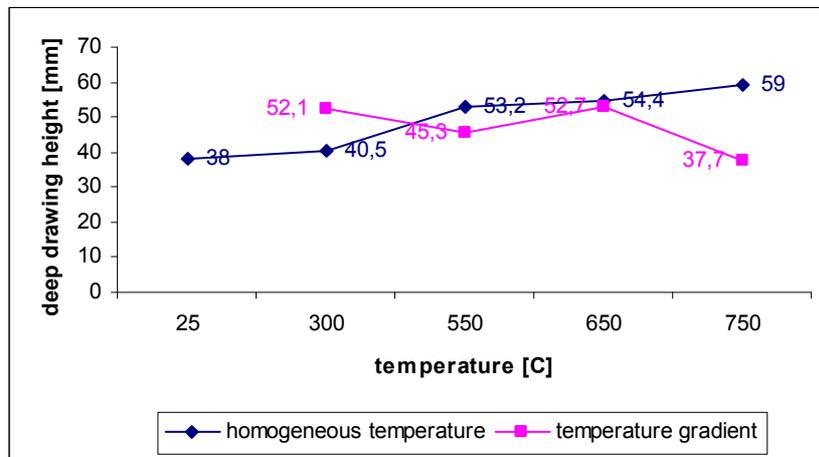


Figure 3. Deep drawing simulation model.

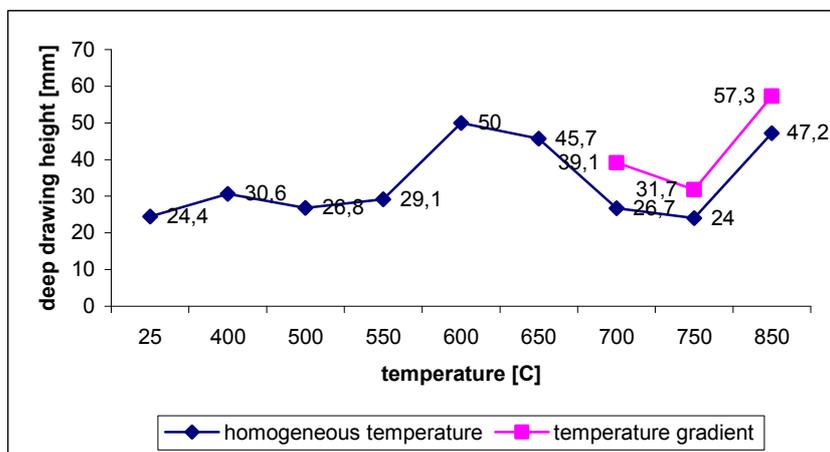
Analysis are realized on half of the geometry because of the planar symmetry of the model. Sheet metal is divided into 5 equal parts in width direction and into 400 equal parts in length direction. Thus, a mesh structure consisting of 2000 quadratic elements is generated. Remeshing option is activated to hinder any unexpected damages since the workpiece is thin. Elastoplastic deformation model is used in the analysis and a simulation is done that considers thermal expansion and heat transfer during deformation. Studies about lubricants in plastic deformation show that lubrication and lubricant type have important effects on deep drawing ratio ( $LDR=d_o/d_p$ ) [10, 11]. In general, a lubricant's coefficient of friction increases when temperature increases. A graphite based lubricant is selected to obtain a deformation environment with low coefficient of friction in hot forming conditions. Coefficient of friction is 0.1 in the analysis. Deep drawing depends on strain rate in a sensitive way. When strain rate is too high, sheet can not flow and damage takes place in sheet after small deformations. In crank presses drawing heights decrease above 120 °C, but there is no such behaviour in hydraulic presses [12]. Thus, hydraulic press machine is used for deep drawing process and a velocity of 5 mm/sec. for sheet deformation stage is chosen. Appropriate temperatures for deep drawing are found by making a lot of analysis at temperatures between the materials warm and hot forming temperatures. Deep drawing of titanium sheet is realized at 25, 300, 550, 650 and 750 °C and steel sheet is realized at 25, 400, 500, 550, 600, 650, 700, 750 and 850 °C temperatures.

### 3. EXPERIMENTAL RESULTS

Graphical distributions of deep drawing heights which are obtained from the computer aided analysis and which are realized under the conditions determined in Chapter 2 are seen in Figure 4. As seen from the graphical data, deep drawability is not proportional with temperature, but maximum deep drawing heights are obtained at high temperatures.



(a)



(b)

Figure 4. Change of deep drawing height with temperature. (a) IMI230 (b) 20MnCr5

From the analysis results, it is seen that temperature gradient applications do not have a clear advantage for IMI230. At 300 °C, deep drawing ratio is elevated with temperature gradient application, but maximum deep drawing height is obtained at 750 °C with homogeneous temperature. For 20MnCr5 temperature gradient application elevated deep drawing height at all temperatures and maximum deep drawing height is obtained at 850 °C with local heatings. In Figure 5 and Figure 6 sample screenshots of the finite element analysis results are given. In these analysis, displacement values in x direction ( horizontal ) are investigated.

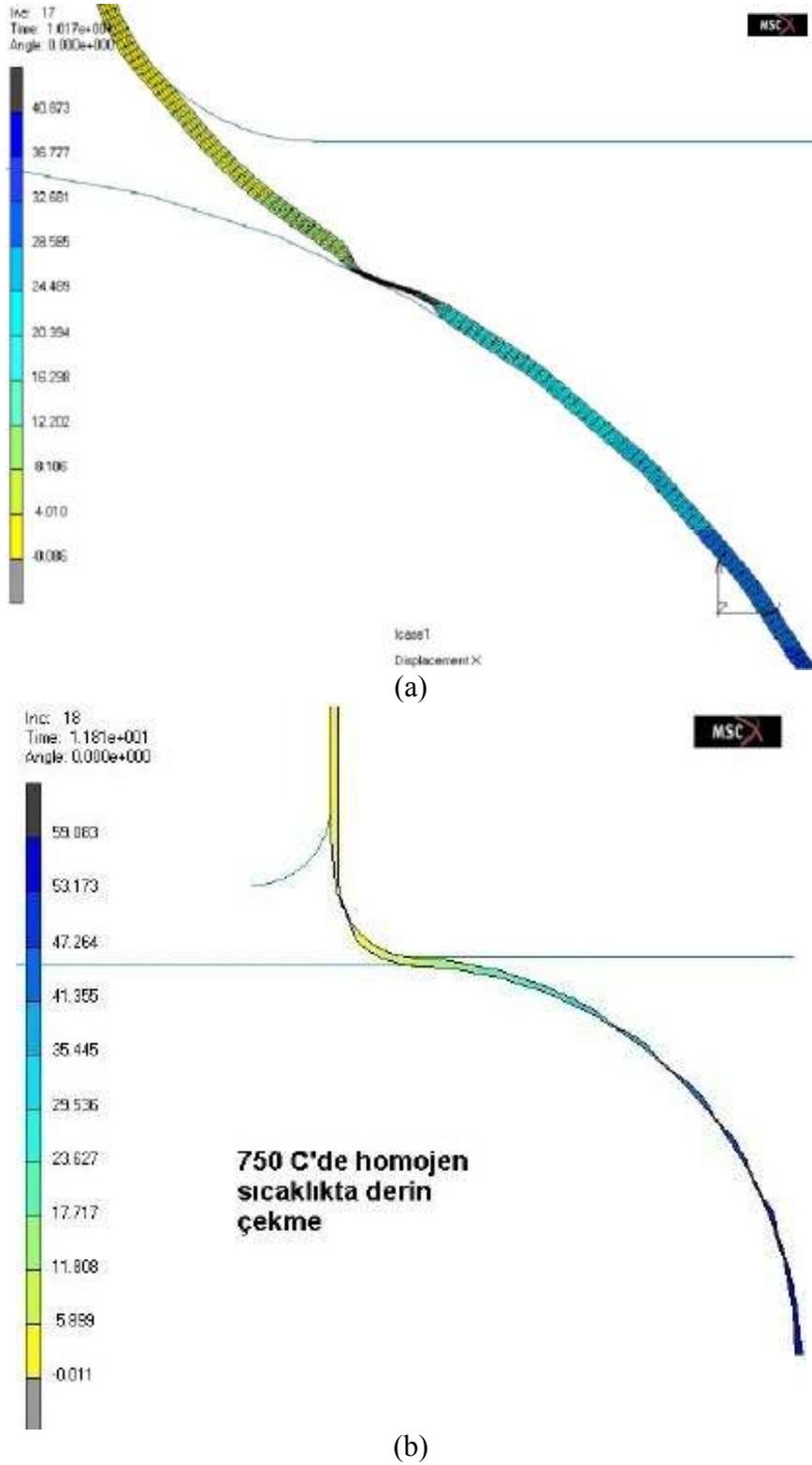


Figure 5. Sample results of the analysis done with IMI230.

- (a) Horizontal displacements of deep drawing at 25 °C homogeneous temperature.  
 (b) Horizontal displacements of deep drawing at 750 °C homogeneous temperature.

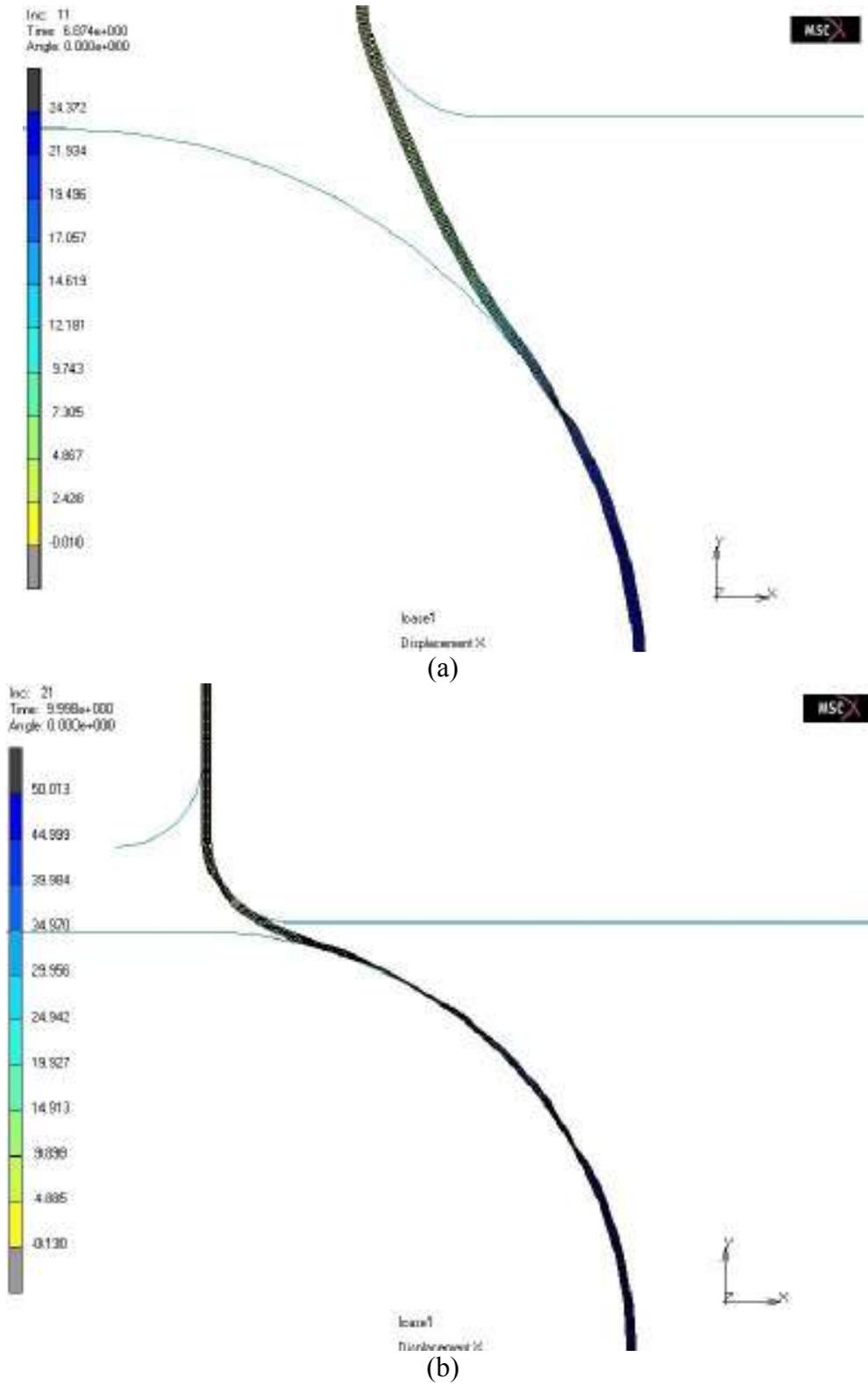


Figure 6. Sample results of the analysis done with 20MnCr5.  
 (a) Horizontal displacements of deep drawing at 25 °C homogeneous temperature.

(b) Horizontal displacements of deep drawing at 600 °C homogeneous temperature.

#### 4. CONCLUSION

Under the lights of the knowledge examined in this study, it would be understood that the deep drawing of high strength materials comprises some difficulties and unknowns, therefore this kind of processes can not be realized in an effective way and it is just possible to execute effective applications at elevated temperatures. Results gained from researches and finite element analysis can be summarized as follows:

- As the deformation temperature increases, flow stress and maximum strength values decrease, maximum strain increases, hardening parameter (n) and strength factor (K) drops. On the other hand, when there is a huge increment at the temperature level, hardening parameter increases suddenly and maximum strain decreases. Increase in strain rate results with an increase in flow stress and maximum strength values, hardening parameter (n), strength factor (K), and decrease in maximum strain. While deformed material's hardness is growing because of hardening at room temperature, warm deformed ( cooled by air ) material's hardness decreases and hot deformed ( cooled by air ) material's hardness increases considerably since microstructural changes.

- Since the plastic deformation properties of steel sheets are related with rolling direction, plastic anisotropy is a significant parameter for the deep drawability topic. Normal anisotropy determines the resistance of steel sheets against thinning while forming. Thus, anisotropical properties of the deformed sheet must be well determined.

- Rolling history and anisotropic properties of the material is removed only when the sheet is heated and thus, the probability of unexpected defects in sheet during deformation decreases. So heating process obtains higher deep drawing ratios without defects like rips and wrinkles by removing anisotropic behaviour of the material and decreasing material's strength.

- Temperature gradient formation during heating process effects formability in a positive way in most applications of sheet metal forming by deep drawing. In some situations, application of temperature gradient increases deep drawing ratio considerably while heating process can not obtain a considerable increase in deep drawing ratio. Generally, punch is held at room temperature while matrix and sheet metal is heated to form temperature gradient. The reason for holding the punch at room temperature is that the most deformed parts of the sheet in deep drawing are the sections nearby the corners of the punch.

- To increase deep drawability with heating, with the dependency of process and material properties, it is required to go up over a certain temperature level. Ideal temperatures show differences from material to material. For this reason, it is required to determine the most appropriate forming temperature with certain research activities before forming process.

- Heating process with temperature gradient provides opportunity to draw steel sheets to higher deep drawing ratio levels with less press forces and to more complex geometries, at the same time it renders possible to get hold of more smooth and homogeneous surfaces.

- The most suitable way to determine the best deep drawability temperature of a sheet material is making analysis at different temperatures by modelling the process via

computer and comparing the obtained results with experimental studies ( performed before ) and if possible with forming limit diagrams of that material.

• It should be possible to attain more certain results and to make more accurate interpretations by comparing the results of this study with the results which will be obtained from the experimental studies which will be realized with the materials that are the subject of our study. It should be appropriate to make experimental and analytical studies with a lot of materials in a wide range of temperature by using different pattern geometries to make the deep drawing process of high strength materials a common application.

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