Some Investigations of Stretching operation of EDD Steel at elevated Temperatures using FEM

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Abstract**—** In the present work the forming limit diagrams for extra deep drawing steel at room temperature and at elevated temperatures have been determined experimentally by conducting stretch forming operations using designed and fabricated warm forming tooling setup. With the help of LS Dyna the formability of EDD steel sheets have been analyzed and compared. These formability limit diagrams were co-related with mechanical properties like strain hardening coefficient and normal anisotropy. Material properties of EDD steel are calculated from room temperature to 450^0C temperatures and effect of these properties like work hardening exponent, anisotropy and strength coefficient of the material are co-related by FLDs at various temperatures.

Keywords**—**EDD steel, FLD, Simulation, stretchforming, Warmforming,

I. Introduction

THE forming behavior of sheet metals has been investigated widely in the last few decades. The formability data analysis of various sheet metals is much important for both scientists and manufacturers to solve the problems occurred during sheet metal forming. So many techniques were used to evaluate and solve such formability related problems. One of such important technique is constructing the forming limit diagram (FLD). It is very effective tool to evaluate the limiting strains in various conditions. The concept of formability limit diagram (FLD) was introduced by Keeler [1] and Goodwin [2] in 1960s. Later on a simplified technique was developed by Hecker [3]. Since then FLDs have been used widely for studying and analyzing the formability of sheet metals. And many more techniques were developed to evaluate the FLDs experimentally and predict the FLDs theoretically in the recent decades. Aluminum alloys are used for automobile and aerospace applications due to their light weight. However steel sheets with high strength have also been extensively applied to improve crash strength without increasing the body weight under strong pressure for the requirements of fuel conservation and saving of energy. In the present work, the formability limit diagrams of EDD steel under stretch forming test at room temperature, 150°C, 300°C, and 450°C were constructed by using Hecker's[3] simplified technique. The die and punch setup has been explained in the earlier work [4]

II. Experimental Method.

A. Chemical composition &Tensile test

The chemical composition of EDD steel sheets used in the experiments was found out by spectrometry and the same is presented in Table 1.Tensile tests were carried out by using electronic universal Testing machine of 5 tonne capacity. The samples were prepared by cutting the EDD sheets along three different directions namely 0◦, 45◦ and 90◦ to the rolling direction of the sheets. The load versus extension data were obtained from these test. The strain hardening exponent (n), the plastic strain ratio (r) (which is the ratio of the width strain to the thickness strain) and planer anisotropy (r^{-}) which are important factors that indicate the formability of the sheet metals were determined from the tensile tests. Using the equation $\sigma = K\varepsilon^{n}$, where σ is true stress and ε is true strain K, strength coefficient was found out. r^{-}Values along three directions namely parallel (0^0), diagonal (45^0) and perpendicular (90^0) to the rolling direction were found out using tensile test.

TABLE I
Composition of EDD steel

Element	% of weight
Carbon	0.048
Silicon	0.83
Manganese	0.39
Sulphur	0.024
Phosphorus	0.019
Chromium	0.027
Stannum	0.004
Copper	0.019
Nickel	0.054
Molybdenum	0.028
Ferrous	Rest

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http://dx.doi.org/10.15242/IIE.E1014050

The normal anisotropy and the planer anisotropy (Δr) were calculated from the r values determined along three directions namely parallel (0^0), diagonal (45^0) and perpendicular (90^0) to the rolling direction using the following expressions:

$$r = \frac{r0 + r90 + 2r45}{4}$$

$$\Delta r = \frac{r0 + r90 - 2r45}{2}$$

B. Stretchforming:

The FLD was evaluated following Hecker's simplified technique [6]. In this method, mainly the experimental procedure involves three stages.

1) Grid marking on the specimen sheets.
2) Stretching the grid-marked samples to failure or onset of localized necking or safe
3) Measurement of strains.

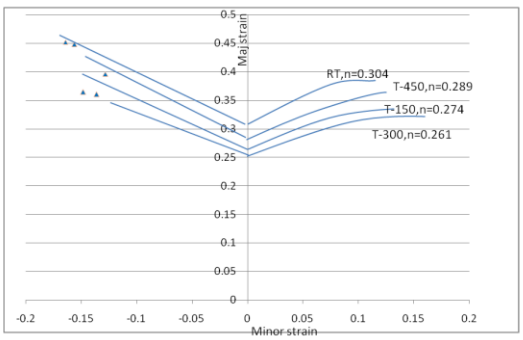

Fig. 1 Formability limit diagrams of EDD steel at different temperature

Grid marking on the EDD steel sheet samples was done using a non-contacting grid of 5 mm diameter circles. The grid pattern was etched on the samples using an electro-chemical etching machine. Punch-stretching experiments were carried out on a 20 tonne (20t) capacity hydraulic press. The punch-die assembly was designed and fabricated depending on the thickness of the sheets. A typical punch-die assembly used in the experiments is shown in Fig[3]. The sheet samples were subjected to different states of stain, i.e. the tension-tension zone, plane strain and the tension-compression zone by varying the width of the sample. In this method samples were cut using sharing machine. The length of the blank was 110 mm and width was varied between 110 to 20 mm insteps of 10 mm. For each blank width, at least five specimens were tested for each temperature to get maximum number of data points. To obtain the maximum values in the magnitude of the negative minor strain, uniaxial tension tests were also done using grid-marked of localized specimens. The blanks were stretched to before necking i.e. safe, the experiments were stopped at the time of onset of localized necking in some cases and continued till fracture in other cases. The circles on the sheet samples became ellipses after stretching, falling into safe, necked and failed zones. The major and minor diameters of the ellipses were measured using a travelling microscope with an accuracy of 0.01mm.Major strains and minor strains were calculated in three regions.FLD was drawn by plotting the minor strain in abscissa and corresponding major strain in ordinate and by drawing a curve which separates the safe region from the unsafe region. The fracture limit and forming limit curves were drawn by connecting the fracture strains for various blanks of a EDD steel sheets. The accuracy of the FLD lies well within a band of ±2% in the engineering strain values

III. Finite Element Simulation

It is a well known fact that strain localization can be captured in finite element simulations of sheet forming processes using shell elements. In this study we have been interested in finding out how the predicted limit strains in the FE models are related to the ones predicted in the various theoretical models previously discussed. In this study, commercial dynamic-explicit FE code PAM-Stamp has been used[7-8]. In the present study, for all of the analysis the geometries of punch, die and blank holder are the same and friction value is taken according to the studies as 0.09.For the finite element models, punch, die and blank holder are considered as the rigid tools whereas blank is the only deformable tool. In meshing the geometries, rectangular shell elements are used with an element size of 2mm. No mesh refinement is used in order to trace the elemental stresses and strains. In addition, 9 integration points through the thickness are used to ensure enough calculation precision.

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IV. Results And Discussion

A. Tensile properties:

TABLE II
Mechanical Properties of EDD steel

Temp	YS	UTS	% elongation	K	n
25	202	337	44	677	0.304
150	188	304	35	577	0.274
300	184	294	29	548	0.261
450	216	329	39	684	0.289

Singh (2010) investigated the properties of EDD steel at various temperatures using 5tonne electronically controlling UTM. For this material it was observed that serrations in the work hardening regime it start appearing between 350°C to 450°C.It was also observed that there was slight increase in the properties like strength coefficient work hardening coefficient and strength of material in this temperature range. It is because of presence of chromium etc which increases the dislocation density within the material due to phenomena of dynamic strain aging. In the present investigation the formability limit diagrams were constructed in this range to see the impact of serrations on the formability.

B. Formability limit diagrams:

The forming limit and fracture limit diagrams for different temperatures are shown in Fig.1.The strain combinations above the FLD line will lead to fracture and those below the line will produce safe region in the drawn cup

FLDs were determined experimentally for the EDD steel sheets by following Hecker's simplified technique are shown in Fig: 1.The above FLDs shown that stretchability of sheet metal is strongly influenced by the value of strain hardening exponent (n).The n values of EDD steel sheets are shown in table.II.From the table it can be seen that the values obtained from true uniform strain in tensile test agreed well with the FLDs obtained at room temperature ,150^{0}C, 300^{0}C, and 450^{0}C mainly in plain strain region. The formability of EDD steel at room temperature and at elevated temperatures are consistent with expectations based on the uniaxial tensile properties. The effect of temperature on EDD steel sheets is observed the level of the FLD is clearly seen, particularly at the plain strain condition. The level of the FLD decreased with increase in sheet temperature, which is approximately coincident with strain hardening exponent (n) at each considered temperature. It also compared with finite element simulation at room temperature and at elevated temperatures. It is approximately matching with experimental forming limit diagrams at all the temperatures. It can be seen the table II that at 450^{0}C there is increase in strength, strength coefficient and relative increase in the work hardening exponent.

C. Finite Element Analysis

Simulated and experimental data is compared. In the simulation it is observed that the displacement at which necking or fracture occurs (limiting dome height) will be higher for smaller width specimen.(or biaxial tension and the dome height will be very small for the specimen 50 to 60mm. It is because during forming a portion on the material on the sides is subjected to compressible hoop stresses. In the deep drawing operation normally we apply hoop stresses but in stretching operation when width of the specimen is somewhere in the middle. Due to this uncontrolled hoop stresses fracture will be appear in the material. Thickness contour of the different sizes of the specimen and different temperature are determined

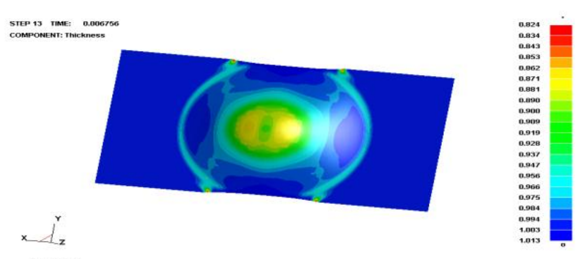

Fig. 2Thickness distribution of EDD steel for blank size 110mm X60mm at 300^{0}C

It can be observed that at high temperature thickness are more uniformly distributed. Von misses stresses contours are presented for different temperature and different width. Figure: 2.It can be seen from the von misses contour that consistently for 50 to 60 mm width of specimen stresses are very high in the region, which subjected to uncontrolled compressible hoop stresses. That is the reason the fracture appears in the earlier stage in simulation. That is the reason dome height is less for intermediate width. It can be seen from the vonmisses contours that by increasing the temperature of the material in the deformed zone vonmisses stresses are slightly less. This is due to decrease in the mean flow stresses. But again at 450^{0}C vonmisses stresses are slightly higher in certain regions due to slightly increase in mean flow stresses.

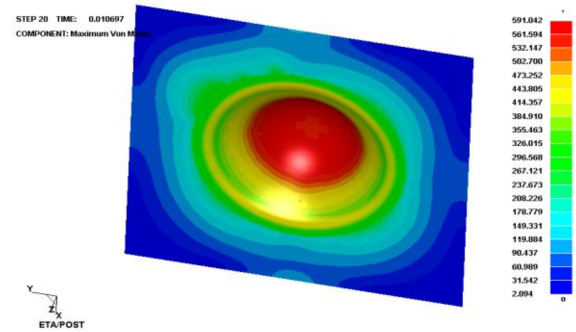

Fig. 3Von-misses stress for the blank size of 110mm X 110mm

The temperature contour that appears in the simulation for the different width of the specimen at different temperature can be seen that in all the contour beyond the drawbead temperature remain the original temperature because in the experimentation dies were heated to required temperature and similar situations were model using material model Mat-106. Some energy will also develop during the deformation of material.

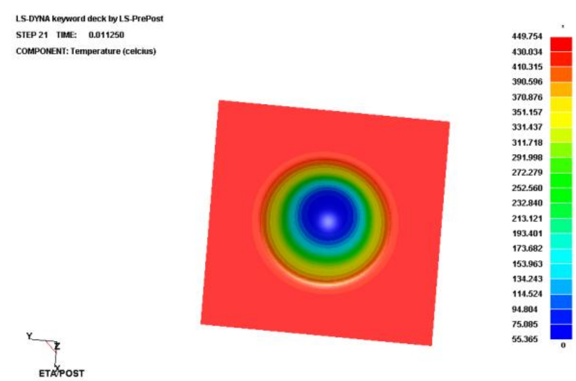

Fig. 4 Temperature contour of EDD steel at 450^{0}C

It can be seen from the entire contour that when width of the specimen increases slightly higher temperature observed in the simulation where this excessive deformation in material like in the region of neck, also in an around drawbead[Fig.4]. Temperature will be higher for higher width because load requirement to deform the material is more.

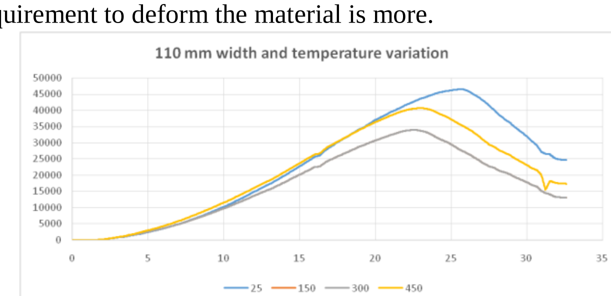

Fig. 5Load-Displacement curves for EDD steel at various temperatures

The related simulation load vs. displacement graphs are extracted from LS-DYNA at different temperature and also different width of the specimen shown in fig.5 and experimental load vs. displacement are recorded by the data execution system. It can be seen from the graphs that by increasing the temperature of the specimen consistently there is decrease in maximum load during stretching operation. But close to 450^{0}C there is slightly increase in the load due to the appearance of dynamic strain regime [7]. It can be also observed from the fig: 5 that load requirement for biaxial tension i.e., stretching 110x110mm specimen load is considerable higher as compared to tension compression specimen. It can be also seen from the diagram that by increasing the width of the specimen there is a larger variation in the load at different temperature. It can be also seen from the diagram that by increasing the width of the specimen there is a larger variation in the load at different temperatures.

V. Conclusion

In order to understand the formability of EDD steel at elevated temperature the formability limit diagrams were constructed at different temperatures using Ni based super alloy dies.EDD steels are naturally formable at room temperature but their formability increases by increasing the temperature primarily because of decrease in the mean flow stresses .Specially at 450oC the material exhibits higher formability due to the dynamic strain regime and same thing is experienced in the formability limit diagrams. It was seen from FLDs that for a substantial portion of sample plain strains were observed at all the temperatures.

To sum up, experimental and numerical studies showed that; analyses which are performed with accurate material modeling with reliable friction coefficient give good results and shows similarity with experimental trials. It is proved that, formability of sheet material caused by wrinkling and tearing can be observed with numerical modeling by using FLD curves. In addition to evaluate the results with FLD curves, the importance of making a comparison between numerical simulated blank with desired geometry is emphasized. To conclude, finite element method is a reliable tool to visualize deformation before real manufacturing to adjust the process parameters. As it is mentioned in each process details such as wrinkling, tearing, sufficient stretching, even the changes in material deformation due to tool location can be obtained with FEM..

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