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Forming limit diagram for interstitial free steels Part I

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Abstract

The suitability of interstitial free (IF) steels of thickness 0.9 and 1.2 mm for press forming operations were examined. The microstructural aspects, tensile properties and formability parameters were studied. Forming limit diagrams were evaluated for the above sheet metals and they were compared. Strain distribution profiles were obtained from the forming experiment. The fracture surfaces of the formed samples were viewed using scanning electron microscope (SEM). Using the fractography, the fracture behaviour and formability were analyzed. The tensile properties and formability parameters were correlated with the FLD. From the analysis, it was found that IF steel having 1.2 mm thickness is superior compared to the other one.

Keywords: FLD; IF Steel; Strain distribution; Void size

1. Introduction

The low carbon steel sheets are widely used for automobile body applications. Interstitial free steels are the steels having very much less amount of carbon and nitrogen. Although aluminium alloys are used for body of the automobiles due to their lightweight, which contributes in the saving of fuel, the demand for vehicle safety makes the users to prefer a material to increase the weight of the automobile body and crashing strength of the vehicle [1,2]. Interstitial free (IF) steels are newly developed materials and have some excellent properties. They are suitable for galvanneal coatings, which is required for automotive body works as given elsewhere [3]. Interstitial free steels are free from carbide precipitates at the grain boundaries [3]. So they have excellent workability and mechanical properties (due to the presence of alloying elements such as Mn and Si). Interstitial free steels are Ti and/or Nb stabilized and they have good drawability [4]. In the recent years, many works have been carried out to develop interstitial free steels with improved properties by understanding the microstructural aspects, which control the deformation behaviour of interstitial free steels as explained elsewhere [5,6]. As a result of these, now IF steels are the materials with good formability and also with stiffness which is required for vehicle safety. So IF steels are now used for automobile body applications and very few research studies have been carried out on this steel with regard to forming limit diagrams and formability aspects. Due to this reason, the present work has been undertaken for the users of these steels.

2. Objective

In the present work, an attempt was made to determine the forming limit diagram for two different thicknesses namely 0.9 and 1.2 mm of IF steels used in automobile industries. Apart from this one, the strain distribution profiles have been obtained for the above steels. Using SEM photographs, the void sizes were measured for various blanks and correlated with shear strain measured from the Mohr's circle radius.

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3. Experiment procedure

3.1. Chemical composition and tensile test

The chemical compositions of these steels supplied by M/s Tata Steels, India, were found out by spectrometry and reported in Table 1. The microstructure of IF steel considered for the study was obtained and it is shown in Fig. 1. Tensile tests were carried out using Hounsfield tensometer. The samples were prepared by cutting along three different directions namely 0°, 45° and 90° to the rolling direction of the sheets [7]. 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 (Δr) 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°), diagonal (45°) and perpendicular (90°) to the rolling direction were found out using tensile test. The normal anisotropy or average plastic strain ratio ($\bar{r}$) and the planer anisotropy (Δr) were calculated from the r-values determined along three directions namely parallel (0°), diagonal (45°) and perpendicular (90°) to the rolling direction using the following expressions:

$$\bar{r} = \frac{r_0 + r_{90} + 2r_{45}}{4} \quad (1)$$

$$\Delta r = \frac{r_0 + r_{90} - 2r_{45}}{2} \quad (2)$$

3.2. Forming limit diagram

Keeler [8] and Goodwin [9] introduced the concept of forming limit diagram (FLD) in 1960s. Since then, it has been widely used for studying the formability of sheet metals. Hecker [10] developed simplified techniques for evaluating FLD. Even in the recent years many works are carried out on FLD [7,11,12]. The forming limit diagrams were evaluated by following standard technique. In this method, samples were cut by shearing. The sample sizes were of 300 mm × 200 mm, 300 mm × 180 mm, 300 mm × 160 mm, 300 mm × 140 mm, 300 mm × 120 mm, 300 mm × 100 mm and 300 mm × 80 mm. In all the samples, grid patterns were printed by chemical etching method. In this experiment, the diameter of the grid circles is 3.5 mm. Forming upto fracture were carried out on a double action hydraulic press of capacity 2000 kN using standard die and punch set up as shown in Fig. 2. The sheet samples were subjected

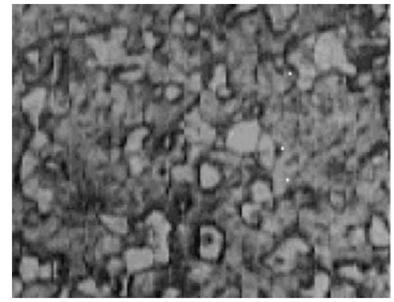

Fig. 1. Microstructure of IF steel – maginification 250× – Nital etchant.

to different state of strain namely tension–tension, plane strain and tension–compression by varying the width of the samples. During forming, circles became ellipses. The major diameters and minor diameters of the ellipses were measured using a traveling microscope with an accuracy of 0.01 mm. Using the major diameter and minor diameter values, the major strains (ε_1) and the minor strains (ε_2) were calculated. The major strains (ε_1) and the minor strains (ε_2) were found out in three distinct regions viz. safe region, necked region and fractured region. 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.

3.3. Strain distribution profiles

Strain distribution profiles were drawn by measuring the major strain and the minor strain of the ellipses at different distances from the pole and plotting the distance from the pole in abscissa and the corresponding major strain and minor strain on the ordinate. The thickness of the blank at different distances from the pole in longitudinal (parallel to the length of the samples), transverse (perpendicular to the length of the samples) and diagonal (45° to the length of the samples) direction were measured and distance from the pole versus thickness strain graphs were drawn. The above procedure was followed for testing of the both sheet metals (i.e., IF steel 0.9 mm thickness and 1.2 mm thickness).

3.4. Fractography

The fractured surface of each blank was viewed by a scanning electron microscope (SEM). The specimens for SEM analysis were cut from the region closest to the origin of the fracture. From the features of the fracture, the nature of fracture and the relation between the features and the formability were analyzed.

Table 1
Chemical composition of the two IF steels (in weight %)

Material	Thickness (mm)	C	Mn	Si	S	P	Al	N (ppm)	Ti	B	Nb
IF steel	0.9	0.0027	0.38	0.009	0.01	0.01	0.047	37	0.042	0.0007	0.046
IF steel	1.2	0.0035	0.4	0.008	0.007	0.044	0.045	35	0.04	0.0008	0.001