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Forming limit diagram for interstitial free steels supplied by Ford India Motors

R. Narayanasamy [a,*], C. Sathiya Narayanan [b]

[a] Department of Production Engineering, National Institute of Technology, Tiruchirappalli 620015, Tamilnadu, India
[b] Department of Production Engineering, J.J. College of Engineering & Technology, Tiruchirappalli 620 009, Tamilnadu, India

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Abstract

Forming limit diagrams are used by the stampers to solve sheet metal forming problems. In practice, sheet metals have been subjected to various combinations of strains. Necking during sheet metal forming sets the limit to which the sheet metal can be formed. Forming limit diagram is an effective tool to evaluate the formability of sheet metals in various strain conditions. The information upon the formability of sheet metals is important for both sheet metal manufactures and user. In this work, the formability of two sheets namely, interstitial free steel sheet of thickness 0.85 mm coated and noncoated, have been studied and their suitability for forming applications have been examined. The microstructural aspects, tensile properties and formability parameters of the above mentioned sheets were studied and the forming limit diagrams were evaluated for the above sheet metals. Strain distribution profiles obtained from the forming experiment have been analysed. The fracture surfaces of the formed samples were viewed using scanning electron microscope (SEM) and the SEM images were correlated with fracture behaviour and formability of the sheet metals. Both the sheets have been found to possess good drawability and stretchability.

Keywords: FLD; I.F. steel; Formability

1. Introduction

The formability of sheet metals have been investigated widely in last five decades. The formability data are much important for both sheet metal manufacturers and users to solve the problems arises during sheet metal forming. Many techniques are used to evaluate the formability of sheet metals. One such important tool is forming limit diagram (FLD). This is an effective tool to evaluate the limiting strain in various conditions. Keeler [1] and Goodwin [2] introduced the concept of FLD in 1960s. Hecker [3] developed simplified techniques for evaluating FLD. Since then FLDs have been widely used for studying the formability of sheet metals and many modified techniques have been developed to evaluate FLD experimentally and predict FLD theoretically in the recent years. Gronostajski and Zimniak [4] worked on theoretical simulation of sheet behaviour in forming process. Banabic and Dorr [5] predicted the forming limit diagrams in pulsatory straining condition. Barata Da Rocha and Jalinier [6] predicted forming limit diagrams of anisotropic sheets. Lian and Baudelet [7] worked on forming limit diagram in negative minor strain region. Since the formability and FLD depend on many factors and conditions of sheet metals, many works have been carried out by others [8–18]. In the present work, the forming limit diagrams of two sheets namely, interstitial free (IF) steel sheet of thickness 0.85 mm coated and noncoated have been evaluated using standard procedure and standard die and punch set up as explained elsewhere [19] using a double action

* Corresponding author. Tel.: +91 0431 2501801; fax: +91 0431 2500133.
E-mail addresses: narayan@nitt.edu (R. Narayanasamy), csathiya-narayanan@yahoo.co.in (C. Sathiya Narayanan).

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hydraulic press of capacity 2000 kN. Although low carbon steels and aluminium alloys are widely used for automobile applications, the demand for vehicle safety makes the users to prefer a material to increase the weight of automobile body and crashing strength of the vehicles [20,21]. IF steels are newly developed materials and have excellent properties. They are suitable for galvaneal coatings, which is required for automotive body works as explained elsewhere. Since they are free from carbide precipitates at the grain boundaries [22], they have excellent workability and mechanical properties. In the recent years, many works have been carried out to develop IF steels with improved properties. In the following sections, the forming limit diagram of IF steel sheets mentioned above and related features are discussed.

2. Experiment procedure

2.1. Microstructure and tensile test

The microstructures of IF steels considered for the study were obtained by following standard metallography procedure and they are 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. The load versus extension data was obtained from these tests. The factors that indicate the formability of the sheet metals such as strain hardening exponent (n) and the plastic strain ratio (r) along three directions namely parallel (0°), diagonal (45°) and perpendicular (90°) to the rolling direction and yield strength and ultimate strength were found out. Using the equation $\sigma = K\varepsilon^n$, (where σ is true stress and ε is true strain), strain hardening exponent (n) and strength coefficient (K) were found out. The normal anisotropy ($\bar{r}$) 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.

2.2. Forming limit diagram

The forming limit diagrams (FLDs) were evaluated by following standard technique. In this method, samples of sizes 300×200 mm, 300×180 mm, 300×160 mm, 300×140 mm, 300×120 mm, 300×100 mm and 300×80 mm were cut by shearing. Circular grid patterns were printed on all the samples by chemical etching method. Samples were formed upto fracture using a double action hydraulic press of capacity 2000 kN with standard die and punch set up. As the sheet samples were subjected to different state of strain viz. tension–tension, plane strain and tension–compression by varying the width of the samples during forming, the circles became ellipses of different sizes. The major diameter and minor diameter of the ellipses were measured using a traveling microscope with an accuracy of 0.01 mm and major strain (ε_1) and minor strain (ε_2) were calculated. The major strain (ε_1) and minor strain (ε_2) were found out in three distinct regions namely safe region, necked region and fractured region in all blanks. 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.

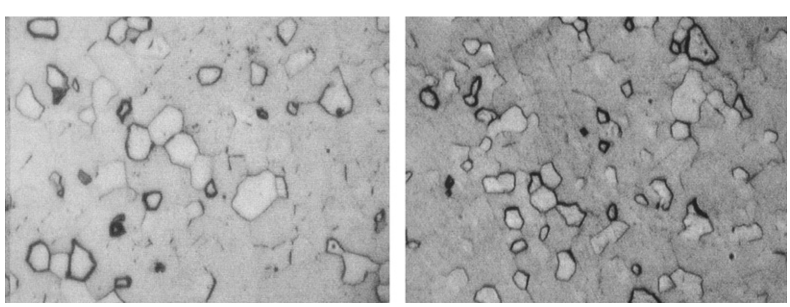

Fig. 1. Microstructure of IF steels—magnification 100×—Nital etched. (a) IF steel of thickness 0.85 mm coated. (b) IF steel of thickness 0.85 mm noncoated.

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

Material	C	Mn	Si	S	P	Al	N (ppm)	Ti	B	Nb
IF steel of thickness 0.85 mm coated	0.0027	0.38	0.009	0.01	0.01	0.047	37	0.042	0.0007	–
IF steel of thickness 0.85 mm noncoated	0.003	0.33	0.013	0.006	0.04	0.04	32	0.044	0.0007	–