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Strain Limit of Extra Galvannealed Interstitial-Free and Bake Hardened Steel Sheets Under Different Stress Conditions

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Abstract: The formability of bake hardened steel (thickness 0.82 mm), and the extra galvannealed IF steel (thickness 0.82 mm) have been studied. The suitability of the above steels for forming applications has been critically examined. The microstructure, tensile properties, and formability parameters of the above sheet metals were determined. The manufacturing process of the steels and the significance with reference to its formability were studied.
Key words: bake hardened steel; extra galvannealed IF steel; microstructure; forming limit diagram; tensile parameter

Forming Limit Diagram (FLD) is an effective tool to evaluate the formability of sheet metals in various strain conditions. The information derived from the FLDs is very much useful for the sheet metal manufacturers and users. Keeler[1] and Goodwin[2] introduced the concept of FLD in 1960s. Hecker[3] designed simplified techniques for evaluating FLD. Since then, FLDs have been widely used for studying the formability of sheet metals and much research has been undertaken, in the recent past. In addition, much theoretical work has been carried out to improve the formability predictions[4-8]. Because the formability and FLD depend on many different factors and conditions of sheet metals, much experimental work has also been done[9-14]. Aluminium alloys are used for automobile applications due to their light weight. However, steel sheets with high strength have also been intensively applied, to improve crashworthiness, without increasing the body weight under a strong pressure for the requirements of fuel conservation and saving of energy. In this work, the FLD of stretch-flanging test (0.82 mm thickness) of bake hardened (BH) steels were evaluated by following the standard procedure, the die and punch set up that has been explained in earlier work. The formability of galvanized interstitial-free steel sheets was studied by Amit Kumar Gupta and Ravi Kumar D[15]. The formability analysis of extra-deep drawing steel was performed by Ravi Kumar D[16]. In BH steel, an experimental and theoretical analysis on the application of stress-based forming limit criterion was done by Butuc M C, Gracioa J J, and Barata da Rocha A[17]. In this work, a comparison between extra galvannealed and BH steel sheets is attempted.

1 Experimental Procedure

1.1 Chemical composition, microstructure and tensile test

The chemical composition of the sheet metals have been supplied by M/s. TATA Steels and presented in Table 1 and Table 2. Microstructures of the steels [Fig. 1 (a) to (d)] taken for study were viewed and captured by the Image analyzer, as per the standard metallographic procedure. Tensile tests were carried out using Hounsfield tensometer. The samples were prepared as per the ASTM standard, by cutting along three different directions, i. e., parallel (0°), diagonal (45°), and perpendicular (90°) to the rolling direction of the sheets. The load versus extension data were obtained from these tests. The important parameters, i. e., the strain-hardening exponent (n), the plastic strain ratio (r) and the strength coefficient (K), along the three direc-

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Table 1 Chemical composition of bake hardened steel (mass percent, %)

Material	Thickness	C	Mn	Si	S	P	Al	N	Cr	Cu
Bake hardened steel	0.82	0.003	0.28	0.008	0.005	0.03	0.055	0.004	0.014	0.004

Table 2 Chemical composition of extra galvannealed IF steel (mass percent, %)

Material	Thickness	C	Mn	Si	S	P	Al	Nb	N	Ti
Extra galvannealed IF steel	0.82	0.005	0.40	0.5	0.015	0.2	0.005	0.020	0.004	0.012

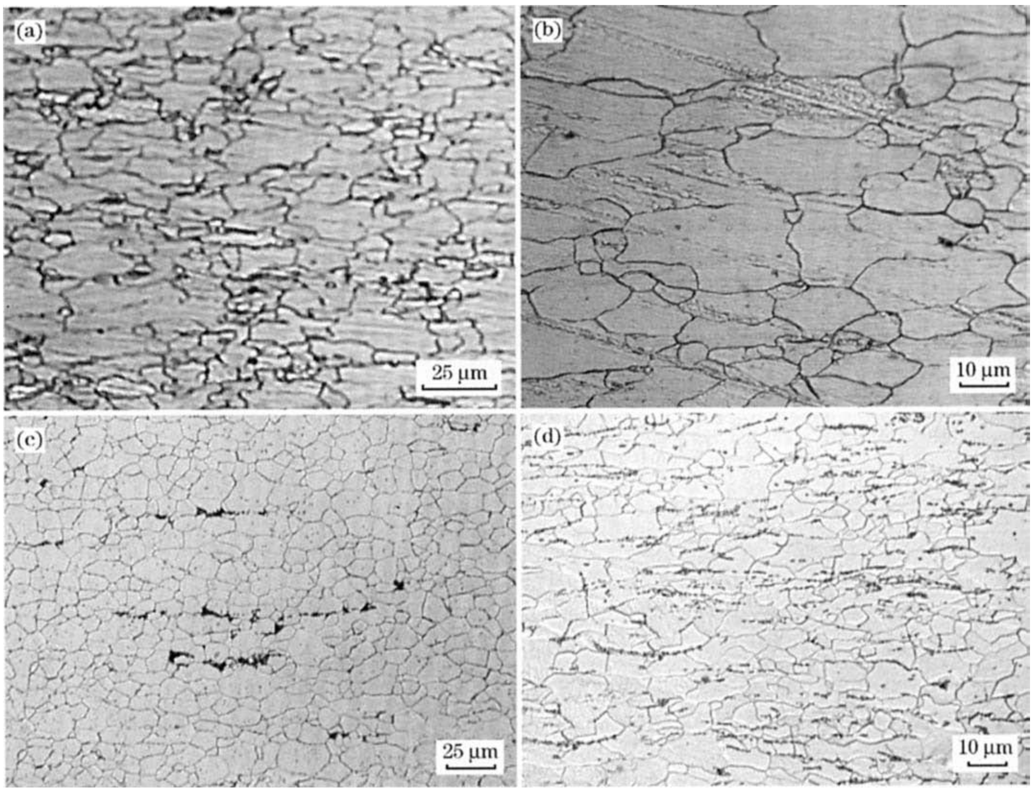

Fig. 1 Microstructure of extra galvannealed IF steel [(a) and (b)], and bake hardened steel [(c) and (d)] (All the samples were etched with Nital)

tions aforementioned were determined from the tensile tests. The normal anisotropy ($\bar{r}$) values were also determined along three directions mentioned above.

1.2 Forming limit diagram

In this method, the samples were cut by shearing. The sample sizes were of 300 mm × 220 mm, 300 mm × 200 mm, 300 mm × 180 mm, 300 mm × 160 mm, 300 mm × 140 mm, and 300 mm × 120 mm. In all the samples, grid patterns were printed by the chemical etching method. In this experiment, the initial diameter of the grid circles was 3.25 mm. Forming operation, up to fracture was carried out on a double action hydraulic press of capacity 2 000 kN. The sheet samples were subjected to different states of strain, i.e., tension-tension, plane strain, and tension-compression, by varying the width of the samples. During forming operations, circles became ellipses. The major diameter and minor diameter of the ellipses were measured using a traveling microscope with an accuracy of 0.01 mm. From the major diameters and minor diameters, major strains (ε_1) and minor strains (ε_2) were calculated. The FLD was drawn by plotting the minor strain in abscissa and corresponding major strain in ordinate.

1.2.1 Extra galvannealing process (extra galvannealed high strength IF steel)

Extra galvannealed interstitial free (IF) steel