

Strain Rate Effect on Forming Limit Diagram for Advanced High Strength Steels

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ABSTRACT

The Forming limit diagram (FLD) is a powerful tool for describing the formability of sheet materials in the automobile industry, which provides fundamental data for die design and Finite Element (FE) simulation. However, traditional FLD testing is typically conducted at quasi-static strain rates from 0.001/s to 0.01/s, which are much lower than the industrial stamping process with strain rates about 1-10/s. In this research, FLDs at various punch speeds (from 1mm/s to 100mm/s or 120mm/s) were obtained for three kinds of AHSS, Quenched and Partitioned steel, Dual Phase 980 and Dual Phase 590 and three kinds of conventional steels, Low Alloy High Strength steel, Bake Hardening steel and IF steel. The results show that FLDs at a typical industrial stamping speed (100mm/s or 120mm/s) are considerably lower than the quasi-static test speed for the Advanced High Strength Steels (AHSS). It is suggested that standard Nakazima test or other formability test should be performed at 1-10/s strain rates in order to obtain the experimental data more close to industrial stamping state, especially for AHSS.

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INTRODUCTION

During the past decades, the advanced high strength steels (AHSS), which provide significant combinations of high strength and good ductility, are increasingly utilized in the automotive industry for the improved safety, fuel efficiency and low-emission of noxious gas. One of the big challenges for the wide application of these new materials is their low formability compared to conventional "soft" steels, for example, IF steels. In this situation, achieving one method which accurately describes material formability behavior becomes more and more important for the die design and Finite Element (FE) simulation work.

The Forming limit diagram (FLD) developed by Keeler and Backhofen in the 1960s [1], has found widespread application as a tool for evaluating formability in the automobile industry. However, the traditional FLD test is commonly conducted at quasi-static strain rates about 0.001-0.01/s, which is much

lower than the industrial stamping state with strain rates about 1-10/s. The failure behavior of materials at strain rates 1-10/s can be significantly different from quasi-static loading because of the deformation-induced heating and strain-rate sensitivity of the material [2]. Percy [3] considered the effect of strain rate on FLDs by explosive forming and stated that FLDs was related to the forming rates. Jie et al [4] reported that no obvious effects of punch speeds on the forming limits were detected for AKDQ. Kim et al. [5] conducted high-speed (strain rate up to 100/s) FLD tests and concluded that the high-speed FLD of DP590 are lower than the static FLD due to the shear fracture. For Al 5XXX alloy, several experiments have been done to investigate the dependence of FLDs on temperature and forming speed [6, 7, 8].

Digital Image Correlation (DIC) is a non-contact optical measurement method for plastically deforming surface and has found widespread use in the auto industry [9, 10, 11]. However, the general DIC equipment can't be utilized for

Table 1. Chemical composition (wt.%) and thickness (mm) for the selected steel sheets

	C	Si	Mn	P	S	Al	N	Thickness
QP980	0.20	1.49	1.82	0.017	0.004	0.05	0.004	1.6
DP980	0.10	0.05	2.2	0.008	0.002	0.04		1.8
DP590	0.08	0.28	0.85	0.009	0.007	0.02		1.6
HC340LA	0.07	0.14	0.8	0.02	0.008	0.04	0.004	1.0
H180	0.002	0.13	0.55	0.04	0.0075	0.03	0.003	0.7
ST16	0.0015	0.01	0.10	0.006	0.006	0.03	0.0015	1.2

Table 2. Mechanical properties for the selected steel sheets (RD)

	Y.S. (MPa)	UTS (MPa)	Total E.L.	n	r
QP980	776	1025	0.17	0.103	0.985
DP980	658	993	0.14	0.151	0.704
DP590	362	645	0.26	0.212	1.199
HC340LA	389	467	0.28	0.145	0.925
H180	272	380	0.295	0.2	2.2
ST16	138	285	0.44	0.267	2.78

industrial stamping rate test since limiting corresponding rates (up to 25 fps) of the ordinary industrial CCDs. For this reason, the traditional circle grid analysis (CGA) method are used here.

In this paper, Nakazima tests were performed at two grades of punch speeds: quasi-static speed (1mm/s) and industrial stamping speed (100mm/s or 120mm/s). Three kinds of AHSS, Quenched and Partitioned Steel, Dual Phase 980 and Dual Phase 590, and three kinds of conventional steels, Low Alloy High Strength Steel, Bake Hardening Steel and IF steel are considered. The FLDs obtained from the tests are compared and the experimental results show that forming limits measured at industrial stamping rates are considerably lower than results collected at quasi-static test speeds for AHSS.

EXPERIMENTAL PROCEDURES

Materials

Three kinds of AHSS including Quenched and Partitioned Steel (QP980) and two Dual Phase Steels (DP980 and DP590) are considered in this research. Three conventional “soft” steels: IF steel (ST16), Low Alloy High Strength Steel (HC340LA) and Bake Hardening Steel (H180) are also selected for comparison. The chemical composition and mechanical properties (rolling direction) for all the materials are shown in Table 1 and Table 2, respectively.

Nakazima Test

Nakazima tests were conducted using a hemispherical punch of a diameter 101.6 mm mounted on the Interlaken Servo Press Machine in order to measure FLDs (It is noted that Marciniak test is another important FLD measurement method

but unavailable for authors' lab. So only Nakazima tests are considered in this paper). The sufficient clamping forces (2500 KN) were provided to prevent draw-in occurring in the flange region. The tests were performed with two punch velocities, viz., a quasi-static speed (1mm/s) and one of two industrial stamping speeds (100mm/s or 120mm/s) in order to evaluate the strain rate effect on the FLDs. The corresponding average strain rate for the quasi-static speed and the industrial stamping speed is approximately 0.01/s and 1/s, respectively.

The specimens are designed based on GB/T 15825.8-2008 [13] to achieve limit strains under different strain paths (Fig.1a) and lubricated with Teflon sheet to reduce the friction. The length direction of all specimens is along the transverse direction. It is noted that two kinds of laser grids are etched on the sample surface to record the surface deformation: circular grids with diameter of 2.5mm and center-to-center distance of 3mm for QP980, DP980 and DP590 and square grids with side length of 2.5mm for H180, HC340LA and ST16 since the experiments were performed by two groups separately. It is believed that the systemic error from different shape grids is negligible.

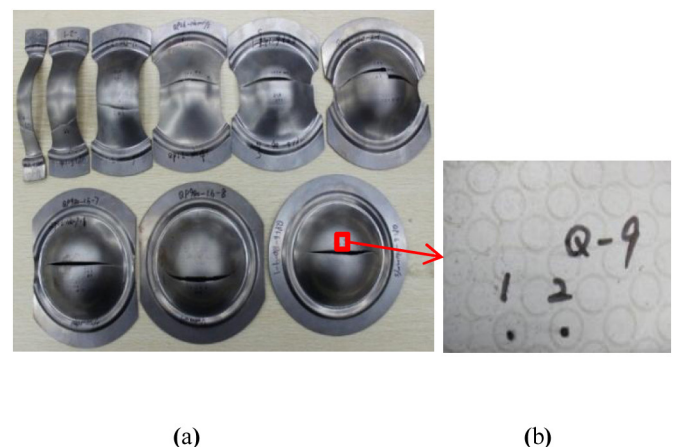


Figure 1. (a) The specimens for Nakazima test (b) Laser etching grids on the samples