

Effect of Prior Austenite Grain Size on Impact Toughness of Press Hardened Steel

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ABSTRACT

Impact toughness (or resistance to fracture) is a key material property for press hardened steel used in construction of the safety-critical elements of automotive body structures. Prior austenite grain size, as primarily controlled by the incoming microstructure and austenitization process, is a key microstructural feature that influences the impact toughness of press hardened steel. In this paper, a special Charpy V-notch impact test is developed to quantify the impact toughness of press hardened steel sheets with various prior austenite grain sizes, by stacking a number of thin sheets via mechanical riveting. Both the ductile-to-brittle transition temperature and upper shelf energy are analyzed in an effort to establish a correlation between impact toughness and prior austenite grain size. Within tested conditions, impact performance shows only a slight decrease as the prior austenitic grain size increases from 18 to 38 microns. On the other hand, grain refinement via micro-alloying in the new 1.8 GPa press hardening steel can significantly increase the impact toughness.

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INTRODUCTION

Ultra-high strength steels are commonly used in construction of the safety-critical elements of automotive body structures for enhanced passenger safety in crash events. One commonly used ultra-high strength steel is 22MnB5 press hardening steel (PHS). It has an ultimate tensile strength of approximately 1.5 GPa with a microstructure consisting of primarily (auto-tempered) martensite after being formed at elevated temperature and subsequently quenched in water-cooled dies [1]. Typical applications of PHS include body structure components that require high strength to reduce intrusion during a crash event, e.g., B-pillar reinforcements, A-pillar reinforcements, and roof rails.

The manufacturing process of a PHS component is a combination of heat treatment and press forming [2]. Complete austenitization must be achieved by soaking a PHS blank above its A_{c3} temperature for a sufficient amount of time prior to hot stamping. This is to ensure that the resulting microstructure will be fully martensitic after hot forming and quenching for maximum strength.

However, prolonged heating or over-baking should be avoided, because it leads to severe surface oxidation/decarburization or excessive thickening of the inter-diffusion layer in aluminum-silicon coated PHS which reduces spot weldability [3]. More importantly, over-baking can significantly coarsen the austenite grain structure, and this may have effects on fracture resistance. Previous research has shown that Charpy impact energy decreases as the average prior austenite grain size (PAGS) increases in quenched and tempered martensitic steels. This is accompanied by an increase of the ductile-to-brittle temperature (DBTT) [4-5]. Recent study

demonstrates that grain refinement by micro-alloying with niobium (Nb) can effectively suppress grain growth during austenitization and significantly improve the associated impact performance [6-7].

Similar to strength, fracture toughness is critical to the performance of vehicle body structures during impact loading. Toughness can be measured by a number of different tests, which are well studied and described by classical fracture mechanics [8]. One commonly used method is the Charpy V-notch (CVN) impact test, in which a prenotched sample is impacted on the opposite side of the V-notch by a striker released from a pendulum.

In this study, the standard Charpy V-notch impact test was modified to evaluate toughness of thin metal sheets that are used for the automotive body structure. Multiple sheets were stacked and riveted together so that Charpy tests can be run on a standard impact test frame. The measured impact energy and ductile-to-brittle transition temperature were directly correlated to the prior austenite grain size of the two different press hardened steels that were heat treated at various temperatures and times evaluated in this study.

EXPERIMENTAL PROCEDURES

Materials and Heat Treatment

Two types of press hardening steels were investigated. The first steel is the widely used 22MnB5, which has a tensile strength of approximately 1.5 GPa after hot stamping. The second investigated steel is grain refined by Nb micro-alloying, with a tensile strength of approximately 1.8 GPa. Both materials have a typical

aluminumsilicon coating of approximately 60 g/m². The substrate compositions have been previously reported [1, 9], and are given in Table 1 below.

Table 1. Reported chemical composition (in wt. %) of the 1.5 GPa and 1.8 GPa PHS samples, from reference [1, 9].

	C	Si	Mn	B	Nb
1.5 GPa PHS	0.23	0.2	1.2	0.002	0
1.8 GPa PHS	0.30	0.3	1.3	0.001	0-0.1

To obtain various prior austenite grain sizes for the 22MnB5 steel, blanks of 150 mm × 900 mm were first heated to peak temperatures of 880 °C, 930 °C and 950 °C at a heating rate of approximately 10 °C/s. The total furnace times, which include the ramp up and soak times at peak temperatures, were 330 s, 390 s, and 540 s respectively. The heated blanks were formed and quenched between flat water-cooled dies. For the 1.8 GPa PHS, blanks of the same size were heated to a peak temperature of 920 °C with a total furnace time of 360 s. These process conditions are hereafter designated as “Min/Min”, “Nom/Nom” and “Max/Max”, and are marked A, B, and C for 22MnB5 as shown in Figure 1. The process condition for the 1.8 GPa steel is marked D in Figure 1.

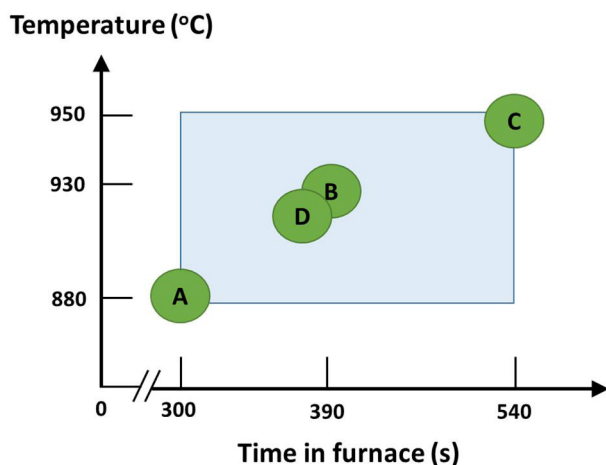


Figure 1. Heat treatment conditions of press hardened steel samples. A: 880 °C/300 s (Min/Min), B: 930 °C/390 s (Nom/Nom), C: 950 °C /540 s (Max/Max) for 1.5 GPa PHS. Condition D is at 920 °C/360 s, which is the “Nom/Nom” for the 1.8 GPa PHS.

Microstructural Characterization

Metallography samples were sectioned from the heat treated blanks for microstructural characterization to determine inter-diffusion layer (IDL) thickness and average prior austenite grain size (PAGS).

In order to measure the IDL, samples were etched using a 3% Nital solution and imaged using a LEICA MEF3A optical microscope. Image analysis software was used to measure the inter-diffusion layer thickness.

To determine the PAGS, another set of samples was etched with a saturated aqueous picric acid solution with the addition of a wetting agent, sodium alkylsulfonate (Teepol) [10]. The etching procedure is described as follows. A saturated solution was first prepared at room temperature by mixing approximately 3 g of picric acid with 100 mL distilled water. Then, 1 mL HCl was added to the picric solution, followed by 1 mL of the wetting agent, Teepol. The solution was then covered with a watch glass and slowly heated on a laboratory hot plate to 65 °C.

Freshly polished cross sectional samples were immersed (face down) into the heated solution for about 30 seconds with slight agitation. Samples were subsequently removed from the etchant, rinsed with methanol, and dried with forced air. To achieve better etching quality, a very light back polish was applied to remove surface smut before re-immersing the sample in the etchant for an additional 10-15 s. This etch-backpolish-etch-backpolish sequence is shown to enhance prior austenite grain boundary contrast in many cases.

The effective prior austenite grain diameter (or PAGS) can be calculated as approximately 1.6 times the mean lineal intercept (MLI) [11]. The later was measured by the standard lineal intercept method over 10 selected fields of views. In this study, approximately 400-500 grains were statistically analyzed to obtain the MLI.

Stacked Charpy V-Notch Impact Test

The stacked Charpy V-notch impact test followed the standard test procedure per ASTM-E23, except that four identical sheet coupons are mechanically riveted together to make a sub-sized sample for an impact test frame. Rectangular coupons of 55mm × 10mm were first extracted from the heat treated PHS blanks using waterjet cutting in the orientation shown in Figure 2. Then, four riveting holes of 3.3 mm in diameter were made using waterjet cutting. The two inner holes were placed about 6 mm away from the notch root and 4.25 mm away from the notched face. The distances of the two outer holes from the notch root and face are 14.5 mm and 5.75 mm. Schematics of a single sheet coupon is shown in Figure 2(a). Rolling direction of the sheet is perpendicular to the notch.

Four coupons were riveted together using four aluminum rivets with steel mandrels to form a stacked sample of 6.4 mm in height. After riveting, the steel mandrels were either fully extracted or cut off. The stacked sample was then ground flat and parallel to a final depth of 10 mm. A standard V-notch with a nominal tip radius of 0.2 mm, was then broached into the stacked specimen at one time. A fully assembled test sample is shown in Figure 2(b).

All stacked Charpy V-notch tests were conducted on a SATEC impact tester with a maximum energy of 400 J at the following temperatures: -125 °C, -75 °C, -40 °C, -25 °C, 0 °C, +25 °C and +75 °C. The standard test procedure, as described in ASTM E23, was followed. Three replicates were tested at each condition.