

Stress-Corrosion Cracking Evaluation of Hot-Stamped AA7075-T6 B-Pillars

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ABSTRACT

High-strength aluminum alloys such as 7075 can be formed using advanced manufacturing methods such as hot stamping. Hot stamping utilizes an elevated temperature blank and the high pressure stamping contact of the forming die to simultaneously quench and form the sheet. However, changes in the thermal history induced by hot stamping may increase this alloy's stress corrosion cracking (SCC) susceptibility, a common corrosion concern of 7000 series alloys. This work applied the breaking load method for SCC evaluation of hot stamped AA7075-T6 B-pillar panels that had been artificially aged by two different artificial aging practices (one-step and two-step). The breaking load strength of the specimens provided quantitative data that was used to compare the effects of tensile load, duration, alloy, and heat treatment on SCC behavior. It was concluded that, when compared to the traditional one-step aging practice, the parts subjected to a novel two-step aging process were similar with respect to SCC resistance.

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INTRODUCTION

As consumer expectations and federal regulations demand increased fuel economy, some automotive manufacturers are considering high-strength aluminum alloys, such as 7075, for body structure applications to reduce vehicle weight because of their high strength-to-weight ratios. AA7075 in a T6-temper has poor room-temperature formability, but hot stamping can be used to successfully form complex components. Hot stamping, as demonstrated by Harrison and Luckey (2014), simultaneously forms and die quenches a B-pillar from AA7075-T6 [1]. Since this process is not the conventional way to form and heat-treat 7xxx-series alloys, the materials thermal history could cause differences in functional metrics including corrosion performance. The work presented below has been focused on the susceptibility of 7xxx-series alloys to stress corrosion cracking (SCC). SCC is a degradation phenomenon that occurs when a susceptible material is under stress while in a corrosive environment. SCC susceptibility of 7075 in chloride-rich environments necessitates characterizing and specifying corrosion resistance to ensure that performance metrics are achieved.

An alloy's thermal history includes the times/temperatures of solution heat treating, the rate at which the material is cooled (quench rate), and temperatures/times associated with artificial aging for obtaining peak strength. In hot stamping the quench rate refers to the rapid decrease in blank temperature during forming such that specific alloying elements are held within the solid solution until the alloy is age hardened [2]. Work by Chen et al. found that quench rates between 1 and 150 °C/s can have significant effect on stress-

corrosion cracking resistance under slow strain rate testing. Low quench rates produced lower ultimate strengths and elongation at fracture, while quench rates of 50 °C/s produced the highest strength and elongation in AA7085 [3]. Keci et al. investigated the effects of quench rate on bulk material properties and found that lower quench rates, in this case 34 °C/s, resulted in below specification yield strengths for AA7075 [4]. In addition to quench rates, changes to the conventional artificial aging practices for 7075, per the MIL-spec [5], can also influence corrosion resistance due to microstructure modification [3]. Improper thermal processing can degrade corrosion resistance in these high-strength alloys. This work subjected hot stamped B-pillars to two different artificial aging methods: (1) a one-step, conventional artificial aging practice and (2) a novel, shorter exposure, two-step artificial aging practice as described by US Patent Application 20150101718A1[6].

Hot stamped B-pillars were tested for SCC susceptibility per the breaking load method, ASTM G139 [7]. This test method combines exposure to a corrosive environment with applied stress for various times. The suitability of this test for determining SCC susceptibility was demonstrated by Johnson et al. [8] and Harrison et al. [9]. The breaking load method is preferred because most test methods for SCC are qualitative and this test method provides quantitative data on both general corrosion and SCC delivering greater statistical discriminatory power than pass/fail corrosion tests. The test has also proven to be capable of distinguishing between temper and alloys differences [10]. Results are discussed in terms of breaking strength (UTS), yield strength (YS), and elongation at fracture.

MATERIAL SELECTION

7xxx-series aluminum alloys were developed to maximize strength, making them an ideal choice for replacing structural steel. Primary alloying elements in AA7075 are zinc, magnesium, and copper. The nominal chemical composition of 7075 is listed in Table 1. The as-received material used in this work was 7075-T6 sheet rolled to 2 mm (0.079 inch) thickness. The T6 temper is a designation associated with aluminum alloys that have been artificially aged to their peak strength.

Table 1. AA7075 composition limits [11].

Element	Al	Zn	Mg	Cu	Fe	Si	Ti	Cr
Weight %	Balance	5.1-6.1	2.1-2.9	1.2-2.0	0.5	0.4	0.2	0.18-0.28

HOT STAMPING

Hot stamping refers to a metal forming process in which an elevated temperature blank is simultaneously formed and quenched by a water-cooled die. The hot stamping approach capitalizes on the low flow stress and high ductility of a solutionized blank. The rapid transfer of heat from the blank to the die allows for alloying elements to be locked in a supersaturated solution state (SSSS). Increased strength of the part is then achieved through artificial aging, which is the precipitation of fine particles. This process has been carried out in practice by Harrison and Luckey (2014) [1] to produce an AA7075 B-pillar.

The conventional, one-step, T6 artificial aging process for AA7075 exposes the material to $120 \pm 5^\circ\text{C}$ for 24 hours [5]. Since such a lengthy heat treatment is not feasible for the high volumes of automotive production, Harrison and Luckey (2015) developed a modified artificial aging practice that delivers peak strength in 5 hours [6]. The accelerated, two-step, artificial aging process exposes the material to $110 \pm 5^\circ\text{C}$ for 2 hours, followed by $165 \pm 5^\circ\text{C}$ for 3 hours. One- and two-step aged materials were denoted as 1AA and 2AA, respectively.

In preparing the material for this work, AA7075 blanks were solution heat treated between $480\text{--}500^\circ\text{C}$ for 10 minutes. The blanks were then removed from the furnace and transferred to the die using automation; the approximate temperature of the blank was 460°C just before the time of die close. Once positioned on the die, the ram of the press travelled at an estimated speed of 240 mm/s with an applied tonnage of 500. Simultaneous blank forming and quenching occurred upon closing of the die. The die remained closed for 15 seconds before releasing the stamped part; the part temperature was between $30\text{--}40^\circ\text{C}$. Upon removal from the press, parts were artificially aged using either the one- or two-step practices. The sequencing of process steps is shown in Figure 3.

EXPERIMENTAL PROCEDURE

Specimen Preparation

Test specimens were cut from stamped B-pillars produced for this work. Specimens removed from the B-pillar captured a wide range of locations and thermo-mechanical histories. The rolling direction of

the sheet was parallel to the length of the B-pillar. As shown in Figure 1, eight specimens were removed in the long transverse axis, and four were removed in the longitudinal axis. Long transverse samples were exposed to the corrosive environment and then tensile tested, whereas longitudinal samples were tested to failure without corrosive exposure to establish baseline pillar and location properties.

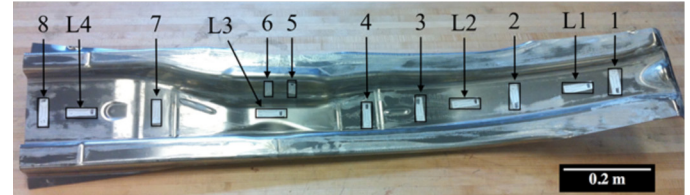


Figure 1. Hot-stamped component with specimen locations marked.

Rectangular coupons were cut from the B-pillars using abrasive cutting disks and a band saw. A fixture was used to drill holes in specimens, as shown in Figure 2A. The specimens were mounted in a fixture and milled to the required shape, ensuring a uniform machine finish on the edges (Figure 2B). Tensile test specimens of a dog bone shape were as described in ASTM E8 [12]. Overall specimen dimensions were 2.500 x 0.750 inches with a gage section 0.655 x 0.250 inches.

Corrosion resistant paint, Corolon V9, was applied to the grip sections to ensure corrosion was localized to the gage section (Figure 2C). Specimens were then mounted in a tensile load frame which is aligned with ASTM G49 [13]. The assembled tensile frame was mounted in a tensioning fixture for loading. The assembled and tensioned load frame with specimen is shown in Figure 2D. The tensioned load frame was then dipped in a melted thermoplastic, ProCoat P-100A, as shown in Figure 2E, to prevent corrosion to the frame and galvanic interactions with the specimen.

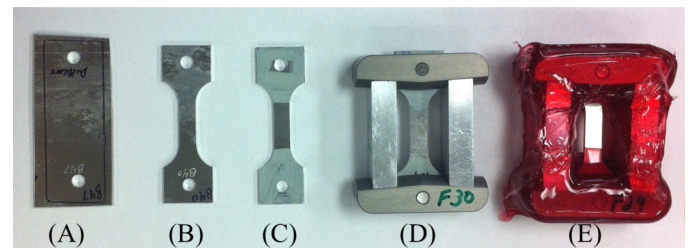


Figure 2. Specimen Preparation Process.

In accordance with ASTM G44 [14], aluminum specimens under a sustained load were exposed to aqueous NaCl for 10 minutes per hour throughout the specified duration of up to 40 days. The aqueous solution consisted of $3.5\% \pm 0.1\%$ NaCl solution by weight with a pH between 6.4-7.2. The environmental chamber maintained $45\% \pm 10\%$ relative humidity with a temperature of $29^\circ\text{C} \pm 1^\circ\text{C}$. Specimens in salt solution are shown in Figure 4. Immediately upon removal from the corrosion bath, specimens were removed from the load frames, rinsed with water to remove the majority of salt residues, and tensile tested to failure within 24 hours. Tensile tests were conducted in accordance with ASTM E8 [12].