Crack Detection on Sheared-Edge of Ultra-High Strength Steel Sheet by Using Acid Immersion

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Abstract. In trimming of ultra-high strength steel (UHSS) sheet, the high strength of the sheet usually results in large fracture and low burnish surfaces on the sheared-edge. For metal stamping industries, large fracture surfaces are unwanted, as it not only deteriorates sheared-edge quality but also leads to delayed-crack. In this study, crack detection by using acid immersion on the sheared-edge of ultra-high strength steel sheet caused by the trimming process was investigated. The ultra-high strength steel sheet of JSC780YN, JSC980YN, and JSC1180YN having different strengths were trimmed and immersed in 35% hydrochloric acid under a controlled time interval. The steel sheet with higher strength was found to produce larger fracture surface after trimming, i.e. more than 50% of the entire sheared-edge is fracture surface. Besides, the larger fracture surface of the steel sheet results in higher crack exposure and higher crack propagation, which in the long run, it can cause failure to the part manufactured using UHSS.

1. Introduction

Recently, there has been a rising awareness of the use of fuel and emissions generated by the increasing number of vehicles, which causes action required to solve both problems, putting the automobile industry under great pressure [1, 2] highlighted CO₂ emissions that causing global warming, require remedial action by automakers to reduce total vehicle weight, and also demand in the safety of car passengers. Due to these problems, some researchers proposed to utilize the usage of ultra-high strength steel (UHSS) on car body parts to achieve the lightweight body part that reduces total vehicle weight, and high strength of parts which essential for crashworthiness [3]. More recent studies that have various structures made up from higher steel grades (800 MPa– 1200 MPa nominal yield strength) also took into account in beams, columns, girders, structural components, and also some critical automotive parts [4].

Utilization of ultra-high strength steel (UHSS) in the body-in-white part is a must since the strength of these materials can exceed more than 1000 MPa of ultimate tensile strength, which is essential for crashworthiness and give protection to the automobile passenger. To manufacture a car part by using this material, it comes with low formability, which gives the tendency of part rejection and cracks, due to its high strength properties [5]. Automobile manufacturers found this problem and apply furnace on
UHSS to achieve phase transformation, but, higher cost of electricity in return, causing cost ineffectiveness [6]. The cold work process approach is under consideration for preventing using a hot work process since it does not involve post-processing that uses furnace [7]. Metal stamping process usually requires another post-processing, such as trimming, in order to remove unwanted parts or scrap [8]. Trimming of metal sheet will give 4 sections of surface, which are rollover, burnish, fracture and burr as shown in figure 1, which are characteristics of the sheared – edge of metal sheet [9].

![Figure 1. Sheared – edge of metal sheet after trimming [9].](image1)

However, in trimming of UHSS, recent studies show crack existence on sheared-edge had been investigated for remedial action to reduce such defect. There also study in the testing of delayed-crack by using HSS and UHSS which shows and forces the crack to grow faster than actual time. [10] were investigated delayed cracking by conducting deep drawing tests in a group of high strength steels (HSS). Their finding shows cracks started from the top of the deeply drawn specimens and propagated longitudinally downwards with delayed cracking, after performing a hydrogen cathodic test. [11] also had investigated the delayed cracking of die-quenched steel sheets that experience small clearance punching die with automatic centring. The specimen then immersed inside a 35% hydrochloric solution to expose the crack at sheared-edge. What had been observed was the comparison of the specimen with automatic centring shows there is no crack, while vice versa for without automatic centring, as figure 2 shows below.

![Figure 2. Illustration of crack at sheared-edge after having acid immersion [11].](image2)
2. Experimental Setup

In this experiment, three different of UHSS sheets, JSC780YN, JSC980YN, and JSC1180YN having the dimension of 300 mm x 600 mm x 1.2 mm in width, length, and thickness, respectively, were trimmed. The mechanical properties of the ultra-high strength steel sheet are shown in table 1.

| Material     | Thickness (mm) | Tensile strength (MPa) | Elongation (%) |
|--------------|----------------|------------------------|----------------|
| JSC780YN     | 1.2            | 813                    | 17.3           |
| JSC980YN     | 1.2            | 1004                   | 12.6           |
| JSC1180YN    |                | 1242                   | 8.1            |

The trimming process is conducted using a conventional shear cutter machine, Sunfluid Malaysia, model 300 A/3. Clearance was set to 10% of thickness ratio, speed of the punch used was 30 mm/s, and trimming condition is without lubricant and at room temperature. The UHHS sheet is held by a blank holder and trimmed using a straight punch as in figure 3. The scrap part of length 10 mm is cut from the original blank as in figure 4, and the trimmed part is taken for crack investigation in the next step.

After prepared all specimens, the specimens are brought into the digital microscope (XOPTRON, model XST60) for a sheared-edge view, where magnifications of the microscope can be adjusted with 6.7, 8.0, 20, 25, 30, 35, 40, and 45 times of magnification. For this experiment, 45 times of magnification was selected for optimum image and crack observation. The placement of specimens under the microscope is illustrated in figure 5. From 300 mm of specimen width, only 7 mm of dimension are captured for different blank strength, and 10 mm for different immersion time, from the right side.

Then, the specimen undergoes the acid immersion test as shown in figure 6. The acid solution was controlled to 35% of concentration and set under room temperature. Two parameters, i.e. sheet strength, and immersion time were controlled to observe the possible different outcomes of the acid immersion. For different sheet strength, observation of crack propagation was carried out on the three types 3 different sheets as in Table 1, where all sheets are immersed for 30 minutes. While for different immersion time, only the JSC1180YN sheet is selected, and the immersion times were set to 3 different time intervals, which are 5, 15, and 15 minutes of immersion time. The specimen is picked up for observation of crack using the digital microscope, and then re-immersed again for the next time interval.

![Figure 3. Specimen placement in trimming machine, (a) Front view, (b) Top view](image-url)
3. Results and Discussions

3.1 Different Blank Strength

Figure 7 shows the sheared – edge of UHSS for 3 types UHSS sheets that have trimming process, while figure 8 shows the percentage of the sheared – edge of 3 types of UHSS sheets. From these illustrations, JSC1180YN shows the highest percentage of fracture area, but lowest in rollover and burr forming. It shows the increase of blank strength leads to lower rollover, burnish, and burr formed, but, increase in fracture area. The reason behind this phenomenon due to the ductility and strength properties. The increase of UHSS strength will give lower ductility. In other perceptions, the higher of UHSS strength shows less tendency of more forming of rollover, burr, and burnish, but the higher tendency of fracture should be formed.
Figure 7. Characteristics of sheared edge, (i) JSC780YN, (ii) JSC980YN, (iii) JSC1180YN (Section A)

Figure 8. Graph of area percentage (%) against sheared edge area.

Figures 9, 10, and 11 show the sheared edge of the trimmed part of the JSC780YN, JSC980YN, and JSC1180YN ultra-high strength steel sheet, before and after immersion in hydrochloride acid. For JSC780YN and JSC980YN, the rolling direction lines show crack propagates along the rolling direction. However, JSC980YN at A, B, C, D areas shows crack on fracture area, while JSC780YN shows no sign of crack at fracture area. While for JSC1180YN, the branch type of crack appeared in whole areas. From observation shows, the higher of blank strength will give higher crack propagation.

Second observation shows for JSC780YN, only one line of the crack along with rolling direction appears, and for JSC980YN, there are a second line of a crack along the rolling direction, which can be seen at figure 9, in area E and F. While for JSC1180YN, there is no line of crack that seems appeared along the rolling direction. Thus, it can be said, the rolling direction will give the effect of crack propagation after trimming for JSC780YN and JSC980YN, and there is no effect of this matter for JSC1180YN.
Figure 9. Sheared – edge image for JSC780YN, i. Before immersion, ii. After immersion

Figure 10. Sheared – edge image for JSC980YN, i. Before immersion, ii. After immersion

Figure 11. Sheared – edge image for JSC1180YN, i. Before immersion, ii. After immersion
3.2 Different Immersion Time

Figure 12 shows the illustration of the sheared – edge of JSC1180YN that having acid immersion with different immersion time. With the increase of immersion time, the crack propagation is getting larger, and the new crack is showed up by an increase of immersion time. From 5 minutes of immersion, it was already showing crack propagation, especially at fracture area, where 1st until 5th cracks were observed. Then, 6th to 8th cracks exposed at 15 minutes of immersion, and at 30 minutes immersion, 9th and 10th cracks initiated. The width of cracks also increases, and the new cracks are exposed to the increase of immersion time. From these observations, it can be said the crack will propagate more, however, from the graph shows the crack will stop to appear if the longer time of immersion test takes place.

![Figure 12. Sheared – edge of JSC1180YN that having acid immersion with different immersion time.](image)

4. Conclusions

From the acid immersion test, two conclusions are line out for this study. First, the higher the blank strength will result in higher crack propagation. The reaction of hydrochloride acid solution on and inside the fracture area was found more dominant on the UHSS sheet having higher strength. The second finding of this study is the propagation of crack is linear with the time of immersion in the hydrochloride acid. As the crack propagated, the crack area was also found widening. For industrial applications, specifically the automotive industry, the present crack on the sheared edge on the real part is a severe problem, which will cause fatigue failure on the part. This problem commonly will lead to part rejection.

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