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Effect of welding and heat treatment on the properties of UHSS used in automotive industry

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Abstract. This paper deals with the undesired effects of the heat treatments on the mechanical properties of (UHSS) Ultra High Strength Steel used nowadays in automotive industry to improve crashworthiness performance of vehicles. The UHSS specimens were extracted from certain parts of the car body and subjected to different heat treatments. Four types of specimens were tested: untreated, welded with metal inert gas welding, heat treated at 800 °C, and heat treated at 1250 °C. All heat-treated specimens showed dramatically reduced values of strength. The results suggest that it is important to follow the official repair manuals avoiding unnecessary welding and improper heat treatments of UHSS. The experiments provide the data necessary for constructing a constitutive model and performing a finite-element analysis of improperly repaired UHSS parts.

1 Introduction

Main challenges in vehicle design are related to the concerns with passenger safety, lighter weight and higher stiffness is required for the vehicle safety. Passenger and, more recently, pedestrian safety requirements entail the use of high energy absorbing materials and a smart geometry to mitigate the injuries in a crash event. Vehicles also need a stiff and durable passenger compartment to reduce intrusions in a crash scenario. A light-weight vehicle structure is ideal for improved fuel economy, ride, and handling of the vehicle (1). Several metal grades have been proposed to replace mild steel in automotive crash applications to achieve a higher strength while retaining the properties of steel, thus, reducing the thickness and weight of components in a vehicle (2). AHSS (Advanced High Strength Steels) were developed to support these requirements and applied in the automotive industry replacing mild steel in structural members. A study by the World Steel Dynamics anticipated that by 2025 the usage of AHSS would reach 23.7 million tons replacing mild steel (3), (4). In vehicles, AHSSs have been used in structural body-in-white parts like A, B, and C Pillars, roof rails, door beams, front and side members; these parts protect from intrusions in the occupant compartment in the event of a vehicle collision (3).

AHSSs are multiphase steels that contain various concentrations of ferrite, bainite, martensite and retained austenite phases; the proportions of which are modified to obtain functional requirements of steel (3), (5).

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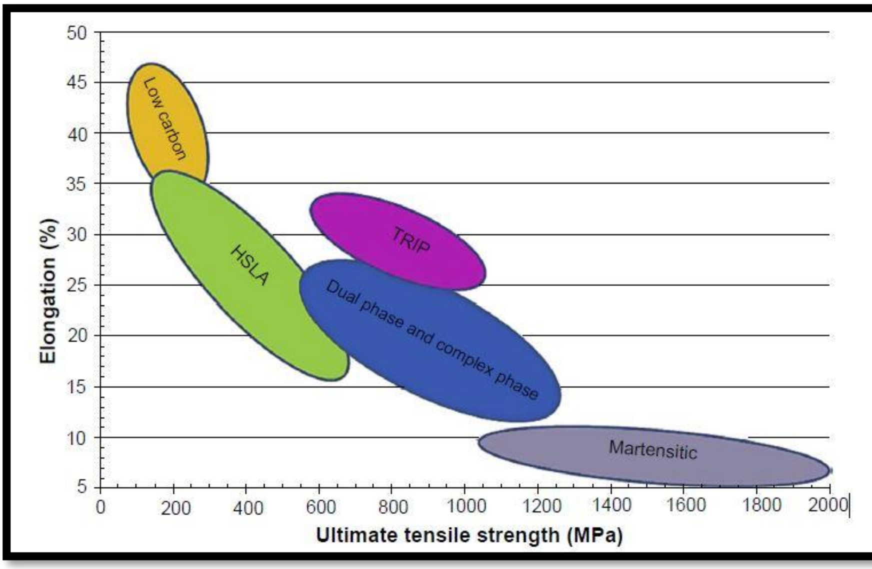

Fig. 1. Strength vs elongation relationship for the first-generation of advanced high-strength steels (3)

- Dual Phase (DP) steels have an ultimate strength roughly between 500 to 1180 MPa; TRIP and CP are available up to 980 MPa. These steel types are used in a car area requiring high strength, high ductility, and good weldability.
- Martensitic steel is currently available with strength in the range of 900-1900 MPa. The yield stress ranges from 900 to 1600 MPa. These steels are alloyed with carbon, manganese and chromium to achieve the required strength. They have high carbon content leading to high stiffness; anti-intrusion properties are used in parts which are not welded in general, for example, bumper and door intrusion beams. They have low elongation (close to 6%) and therefore are not considered for energy absorption applications. The use of this steel type poses welding and forming challenges because the heat produced in these processes alters the microstructure of the material thereby changing its mechanical properties. As per a study conducted on the heat treatment of these material the HAZ (Heat Affected Zone) produced by welding causes significant austenite growth followed by phase transformation in the material (3).
- Boron Steels are produced by adding higher carbon percentage in the range of 0.2 to 0.25% with approximately 1.2% manganese and 0.0005-0.001% boron increasing the hardenability of steel (6). This type of steel has high deformation resistance, thus making it suitable for the use in passenger safety cage applications.

Collision repair for AHSS has been a challenge for automakers leading to new repair procedures outlined in repair manuals to prevent undesired heat treatment of structural parts. These parts are recommended to be either replaced or repaired strictly according to the procedure in the manual. The report published by the American Iron and Steel Institute (7) presents the results of the collaborative project with General Motors which investigates the repairability of AHSS used in automobiles in order to determine the crashworthiness response of a vehicle after proper repairs were conducted on the vehicle parts. The micro-structure changes are observed in the material due to application of heat; the material reverts to soft equilibrium phases which reduces its crashworthiness response in a crash event (7). Several studies have been conducted to support the hypothesis that the vehicle crash response is negatively affected due to improper repairs conducted on the vehicles (8), (9). Material behaviour changes are reported after improper collision repair related to welding or heat treatment on the vehicle.

The literature review shows that there has been insufficient data for developing a material card to conduct FE simulations for an improperly heat-treated vehicle member. In this study, material characterization of coupon samples cut out from vehicle structural members was conducted to investigate the baseline material properties of the steel-type used in the parts. Welding and heat treatment of these samples was conducted to determine the impact of these processes on the strength and stiffness of the material. This coupon testing approach forms the basis for the development of a material model to replicate improper collision repair on a vehicle.

The coupon samples used in this study underwent tensile testing in a UTM (Universal Testing Machine) in the laboratory at the University of Agder and stress-strain curves were derived using the data from the extensometer and DIC (Digital Image Correlation) measurements.
The next section on this paper explains the methodology of the experiment and the results/observations from this experimental data.

2 Methodology

The UHSS coupon test samples used for tensile testing were cut out from the parts of the car, structural parts are shown in Fig. 2 and were further cut into dog bone samples using water jet cutting to obtain the correct sample size. The standard specimen size selected for the tensile test specimen is an ASTM (American Society for Testing and Materials) E8 dog-bone specimen as shown in Fig. 3. The steel samples were taken from a car which uses UHSS for structural durability of its members, however we are not aware of the steel type and properties used in the vehicle and assume that it is boron steel referring to the metal in the sequel as UHSS.

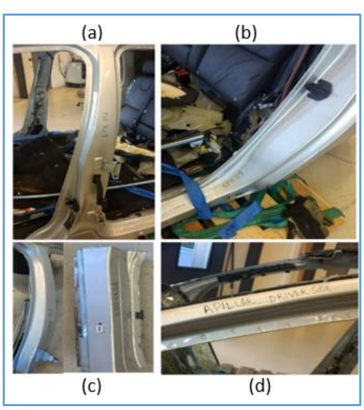

Fig. 2. Vehicle structural members using UHSS (a) B-Pillar, (b) C-pillar, (c) Rocker, (d) A-Pillar

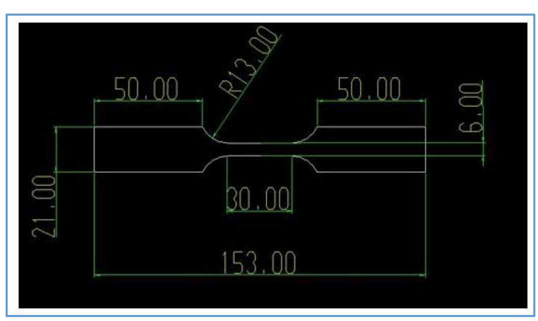

Fig. 3. Dimensions of the specimen used in the tensile test (ASTM E8)

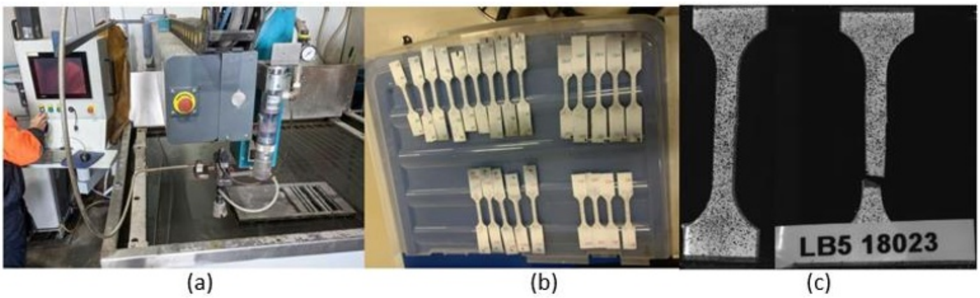

Fig. 4. (a) Water jet cutting of the samples, (b) dog-bone samples, (c) speckled sample for DIC

Fig. 4 (a) above shows the water jet cutting process. The samples were further divided into 4 types as the table below (Table 1).

Table 1: Sample Types used in this study

SI No	Sample Type	No of samples
1	Baseline	4
2	Welded Sample	4
3	Heat Treated at 800 °C	4
4	Heat Treated at 1250 °C	4

2.1 Sample Preparation

- Baseline Sample: After the water jet cutting the dog bone samples were used as a baseline UHSS sample. The samples were measured to ensure same thickness and test area to get consistent results for all tests.
- Welded Sample: The coupon was cut at the centre of the reduced section and welded using the metal inert gas Argon-CO_2 (19l/min at 18V,106-114 Amp, filler rate; 3.5 mm/min). The two parts of the coupon were joined by a single V butt joint and grinding operation was conducted to make the sample edges smooth.
- Heat Treated at 800 °C: The baseline sample type was heat treated in a furnace at 800 °C for a period of 3 mins and then the sample was cooled with air before tensile testing. The intent was to introduce a change in the microstructure of the base material and test its behaviour.
- Heat Treated at 1250 °C: The process followed is similar to the heat treatment at 800 °C: leaving the sample in the furnace till the temperature reaches 1250 °C and keeping the furnace temperature fixed prior to removing the samples for air cooling process.

The samples produced with the processes described above were of a similar dimension. However, since the samples were cut out of vehicle parts, internal stresses could be present in the samples due to the manufacturing process of these parts. Therefore, the results might deviate from the manufacturer's baseline material data. The goal of the study is to detect any change in material properties in the vehicle parts during the repair process.

One of the best practices involved in conducting DIC is speckling the samples with a random pattern so that the samples can be identified by the camera (10). The coupons were speckled with a spray gun before the tensile testing process as shown in Fig. 4 (c). The tensile test was conducted at a constant loading rate of 0.3 mm/s and the loading was terminated when the specimens underwent a fracture. The machine is equipped with load cell, build-in position sensor and clip-on LVDT-based extensometer with a measurement range of 25mm to 30 mm.

3 Experimental Results

The data from the extensometer and DIC were postprocessed to obtain the stress-strain curves for the samples as shown in Figure 5. The load-elongation curves were constructed using a combination of machine build-in sensors and extensometer displacement data; compliance correction was applied where necessary.

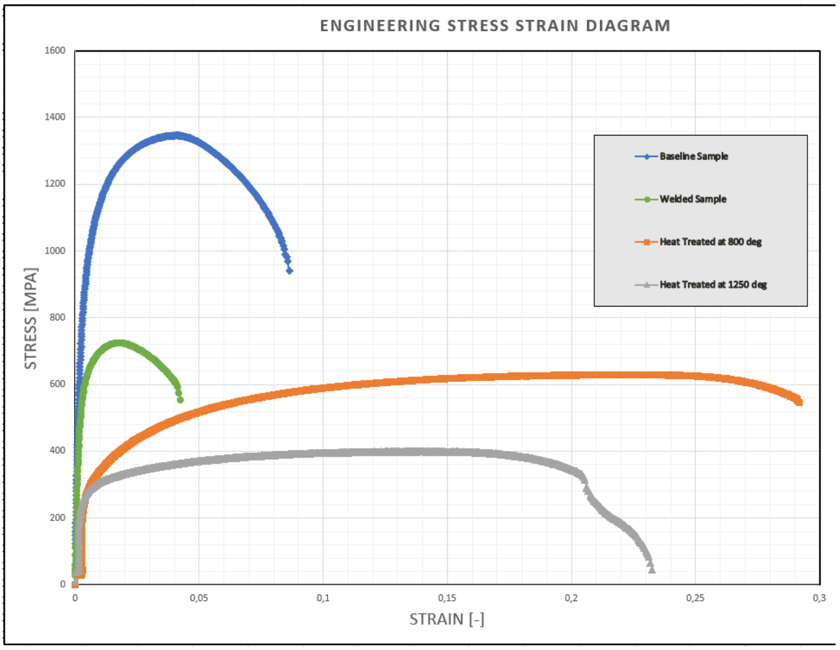

Fig 5: Engineering Stress Strain Diagrams for (i) Baseline Sample (ii) Welded Sample (iii) Heat Treatment at 800 °C Sample (iv) Heat Treatment at 1250 °C Sample

Table 2 shows the yield stress, ultimate stress, and ultimate strain in the four sets of samples; the mean values for individual tests are presented.

Table 2: Material properties derived from the test data graphs

SI No	Type of Sample	Yield Stress (MPa)	Ultimate Stress (MPa)	Ultimate Strain
1	Baseline	1188	1325	0.043
2	Welded Sample	730	758	0.016
3	Heat Treated at 800 °C	386	582	0.191
4	Heat Treated at 1250 °C	311	383	0.100

3.1 Discussion

A high yield strength of a material indicates its capacity to withstand extreme structural loads before it deforms or fails. The results of the tensile tests indicate that the baseline sample has a high yield strength higher than 1100 MPa. The high yield strength value helps the vehicle structure to withstand the impact of a frontal or side crash event. However, the coupons which underwent welding or heat treatment before the tensile test show lower yield strength and ultimate strength values indicating reduced structural integrity in the vehicle occupant cage. This can be fatal to vehicle occupants in a crash; it may also lead to a change in the load distribution in the vehicle structure and cause more intrusions in the passenger compartment. It is also observed that the strains in the welded sample were lower compared to the baseline and heat-treated samples indicating lower ductility; this can be attributed to the filler material used for the welding.

The material parameters defined can serve as a starting point for developing a material card to be used in an explicit solver software like LS Dyna. The experimental values for improper heat treatment of structural members presented in this paper can be used to simulate an unprofessional repair in vehicles. FE simulations with the material card (e.g., MAT 24: Piecewise Linear Plasticity used in LS Dyna) developed using these reference values are out of scope for this paper.

There are several important observations and assumptions made during this study, for instance:

- The coupons may have internal stresses resulting from the manufacturing process of the parts, so the baseline results may not match the manufacturer data.
- The type of welding of the samples can significantly differ during repair, hence the material properties might vary due to the variations in the welding process affected by the welding conditions, experience of the welder, and the type of a joint made.
- The authors also recognize the minor variations between sample sizes because the samples were cut out from the vehicle parts and subsequently underwent water jet cutting to extract coupons; these variations can also introduce errors in the stress calculations. The tensile testing process on the UTM can also include minor variations which remain unaccounted for. To account for some of these variations, we conducted the minimum of 3 valid tests for each sample type and took the mean values.

4 Conclusions and Next Steps

In this study we observed the changes in the microstructure of UHSS samples subjected to tensile testing in a UTM. It was concluded that the lower yield strength of the material coupons results from the welding or heat treatment of the samples; it causes the change in the properties of steel and may lead to a poor crashworthiness response of a vehicle under impact.

It would be interesting to conduct a spectral analysis on the samples to understand the microstructure changes in more detail, and a hardness test to further explore the material characteristics of the samples. It is also of interest to investigate microstructure around the weld to determine the reason for low ductility in the sample. The material data generated from this research can be also used to generate a material card to simulate the material behaviour in a non-linear full vehicle crash using an FE solver.

5 Acknowledgement

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