Materials Science & Engineering A 716 (2018) 92–98

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Effect of prior austenitic grain size and tempering temperature on the energy absorption characteristics of low alloy quenched and tempered steels

Elakkiya Mani, Thendralarasu Udhayakumar[1,*]

Corporate Technology Centre, Tube Investments of India Ltd., India

ARTICLE INFO

Keywords:
Low alloy steel
Energy absorption
Prior austenitic grain size
Induction hardening
Tempering temperature

ABSTRACT

The aim of the present work was to investigate the combined effect of prior austenitic grain size and the tempering temperature on the energy absorption characteristics of low alloy quenched and tempered steel. High frequency (HF) electric resistance welded tubes made of Boron added low carbon steels were used for the study. Induction hardening at two different temperatures (above upper critical temperature) led to two different prior austenitic grain sizes 20 µm and 100 µm. Both the set of samples were subjected to conventional tempering at different temperatures and it resulted in variation in the distribution and morphology of the carbides. Microstructural evolution at each tempering temperature, carbide morphology and distribution of carbides was investigated using SEM. Low temperature tempering leads to precipitation of rod like carbides and with increase in tempering temperature the carbide morphology turns spherical followed by carbide coarsening at higher temperatures. Three point bend test of the tempered samples was carried out using Schimadzu Universal testing machine to determine the energy absorption characteristics. Test results indicate that optimum combination of high energy absorption and better mechanical properties was delivered by tempered martensite with fine spherical carbides and fine prior austenitic grain size. Thus the work established the correlation between energy absorption; prior austenitic grain size and tempering temperature in low alloy quenched and tempered steel.

1. Introduction

The emerging automotive industry demands significant improvement in three main areas: Fuel efficiency, Safety, Emission gas regulations. Fuel efficiency is mainly a function of weight of the steel parts, which is controlled by gauge and design. Safety performance is determined by the energy absorbing capacity of the steel used. Low alloy quenched and tempered steels are currently the leading choice of material for crash members owing to their high strength and energy absorption characteristics. Side impact beam is one such crash member, which plays an important role in preventing the passenger from injuries during accidents. The major requirement of the beam is crashworthiness, the ability to absorb energy during impact loading.

Nowadays, High frequency electric resistance welded steel tubes are being used as safety critical members like side impact beam in passenger cars and they have completely substituted the conventional cold stamped channels. Thin walled tubes are generally preferred for side impact beam application to improve fuel efficiency and enhanced energy absorbing capability. The material composition, geometry or profile of the tube, processing parameters and heat treatment are the important factors contributing to the performance of the component.

Several studies have already been carried out on the effect of different geometrical parameters of tubes and material on its energy absorption characteristics. In the case of aluminum thin-walled structures of square and circular cross sections, slight increase in wall thickness of the material is directly related to the energy absorption behavior of the beam [1]. In aluminum corrugated tubes, the quasi static crushing behavior is affected by corrugation geometry. Corrugations make the collapse of circular thin walled tubes uncontrollable under axial loading. The depth of corrugation in the corrugated tubes influences the load required for deformation [2]. In 15B22 steel, excellent combination of strength and elongation was delivered by extremely fine high frequency induction hardened martensite compared to conventional hardened martensite. The study showed that compared to heating rate, quench temperature has more impact on the prior austenitic grain size of the as-quenched steel. Finer prior austenitic grain size results in ductile dimple fractograph after tensile test, indicating an excellent ductility [3]. A comparative study on microstructural evolution and the corresponding variation of the mechanical properties tempered by induction heating against conventional salt bath heating has been carried

* Corresponding author.
E-mail address: thendralarasu@tii.murugappa.com (T. Udhayakumar).
[1] Postal address: Corporate Technology Centre, Tube Investments of India Ltd, Post Bag No-4, Avadi, Chennai-600 054, India.

https://doi.org/10.1016/j.msea.2018.01.020
Received 8 August 2017; Received in revised form 4 January 2018; Accepted 5 January 2018
Available online 06 January 2018
0921-5093/

out. It reveals that spheroidization of carbides takes place faster in the case of induction tempered steel than salt bath tempered steel [4]. The effect of tempering temperature on the impact toughness of 0.3 mass% carbon martensitic steels with two different prior austenite grain sizes was investigated. Different prior austenitic grain sizes gives rise to variation in carbide size distribution during tempering at 723 K and it results in difference in impact toughness of the material [5]. The possibility of using other materials like Magnesium for side impact beam application has also been explored [6]. Increase in ultimate tensile strength results in increase in the energy absorption during collapse. In tubes, increase in outer diameter has lesser impact on the energy absorption when compared to increase in thickness [7].

The present work investigated the effect of prior austenitic grain size on the energy absorption characteristics of low alloy quenched and tempered steel with additions of Boron. The effect of tempering temperature on the mechanical properties and energy absorption characteristics was also studied.

2. Experimental procedure

Cold rolled low alloy steel with strength level of 500 MPa and the chemical composition which is listed in Table 1 was used for the study. Addition of Boron results in enhancement of hardenability and strength without loss of ductility [8].

Low alloy steel tubes of outer diameter 25.4 mm and thickness 1.6 mm were manufactured through the conventional high frequency (HF) electric resistance welding route. The key welding parameters like heat input, squeeze pressure were carefully monitored during the tube manufacturing process to obtain optimum bond strength and weld quality. Induction hardening of the tubes was carried out using vertical scanning induction machine. The tube samples were induction hardened at two different temperatures (above Ac_3 temperature) 1153 K and 1353 K and then they were water quenched. Prior austenitic grain size of the induction hardened and quenched sample was evaluated using different etchants. After Induction hardening, the samples with different prior austenitic grain sizes were tempered at 623 K, 723 K, 773 K and 823 K with soaking time of 15 minutes in an electric heating muffle furnace without controlled atmosphere. Microstructures of the steel in different heat treatment conditions were examined using ZEISS Light optical microscopy and JEOL Scanning electron microscope. Carbide morphology of the tempered samples was analyzed using SEM. Tensile samples were extracted from the tubes at different heat treatment conditions as per the standard ASTM E8. Testing was carried out using universal testing machine (UTM) to determine the mechanical properties like yield strength, ultimate tensile strength and uniform elongation.

2.1. Three point bend test

The static three point bend test was carried out using UTM to determine the energy absorption characteristics of the tubes under different heat treatment conditions. The experimental test setup is shown in Fig. 1. The test is also termed as Intrusion test since it determines the extent of tube collapse. During the test, the tube is supported over rollers for a span of 600 mm and load is applied on it by a ram whose radius of curvature is 150 mm. Tube samples of dimensions outer diameter 25.4 mm, thickness 1.6 mm and length 845 mm are subjected to test. The ram is moved over a distance of 150 mm from the point of contact with the tube at a velocity of 300 mm/min [9]. The area under the force – displacement curve during displacement of 150 mm is equal to the energy absorption capacity of the tubes [10,11]

Table 1
Chemical composition of the steel.

Element	Weight %
Carbon	0.21
Silicon	0.42
Manganese	1.1
Phosphorus	0.01
Sulphur	0.002
Chromium	0.2
Aluminum	0.02
Titanium	0.03
Boron	0.0015

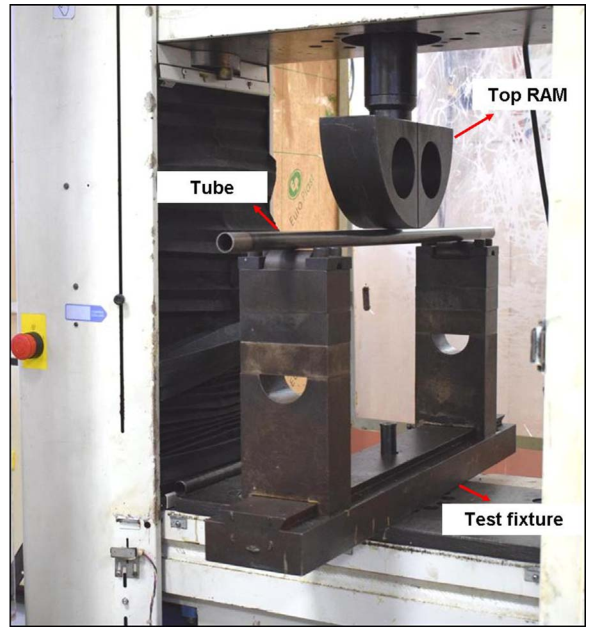

Fig. 1. Image showing the three point test set up in Universal testing machine.

3. Results

3.1. Microstructural characterization

Optical micrographs of the low alloy steel tubes in the as quenched condition show the presence of low carbon lath martensitic structure. Fine lath martensitic structure was observed in the samples induction hardened at 1153 K (refer Fig. 2a) and coarse lath martensitic structure was observed in the samples induction hardened at 1353 K (refer Fig. 2b). The martensite packets were coarser in the later due to higher hardening temperature.

3.1.1. Prior austenitic grain size determination

Fig. 3a and b shows the prior austenitic grains of the samples hardened at 1153 K, giving prior austenitic grain size of 20 µm and at 1353 K giving the prior austenitic grain size of 100 µm respectively. The above mentioned prior austenitic grain size reveals the significance of hardening temperature. Various etchants were used to reveal prior austenitic grains and also different procedures to best reveal prior austenitic grains were investigated [12,13].

In the present work, the prior austenitic grain boundary was contrasted using modified Winsteard reagent. The water-based reagent was mixed in two parts because picric acid is very difficult to dissolve in water. Solution containing 2gms of picric acid and 10 ml ethyl alcohol solution was prepared initially. The prepared solution was added to water, and sodium dodecylbenzene sulfonate was added as wetting agent. For effective etching, the reagent was used hot between 60 °C and 70 °C and five drops of hydrochloric acid was added. Etching was done by placing the beaker in an ultrasonic stirrer.