Defence Science Journal, Vol. 65, No. 4, July 2015, pp. 339-342, DOI : 10.14429/dsj.65.8749

Microstructure and Mechanical Properties of Laser Beam Welds of 15CDV6 Steel

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ABSTRACT

The present study is concerned with laser beam welding of 15CDV6 steel, that is in the hardened (quenched and tempered) condition before welding. Autogenously butt-welded joints are made using carbon dioxide laser with a maximum output of 3.5 kw in the continuous wave mode. Weld microstructure, microhardness measurement across the weldment, transverse tensile properties, and room temperature impact properties of the weldment have been evaluated. The fusion zone exhibits a epitaxial grain growth. The microstrutural features of heat-affected zone and fusion zone vary, due to different thermal cycles for which these were subjected during welding. The average weld metal hardness was 480 Hv. The observed hardness distribution across the welds were correlated with the microstructures. The welds exhibited lower toughness of 50 joules as compared to parent metal of 55 joules and the tensile strength values of the welded specimens are close to that obtained for sheet specimens.

Keywords: 15CDV6 steel, laser beam welding, microstructure, mechanical properties

1. INTRODUCTION

15CDV6 steel, a member of high-strength low-alloy steel family, is a low carbon bainitic steel[1]. This steel contains low concentrations of chromium, molybdenum and vanadium as alloying elements. It possesses good strength-ductility combination and excellent weldability[2,3]. The alloy finds many applications in the aerospace and motor sports industries in such components as roll cages, pressure vessels, rocket motor casing and sub-frames.

15CDV6 steels obtain their strength by austenising at 975 °C ± 5 °C followed by oil/water/forced air quenching, and tempering at 640 °C ± 5 °C. Generally, quenching and tempering are well-established means for strengthening of steel. During tempering, precipitation of a fine dispersion of alloy carbides occurs, this results in stengthening of steel. The tempering treatment would be dictated by the strength and toughness requirements. From the literature, it is found that the strength and hardness decrease as the tempering temperature and holding time were increased. However, the effect of tempering temperature is more significant than that of holding time. But the ductility of material increases with the tempering temperature and holding time.

It possesses very high strength-to-weight ratio, along with good toughness. The microstructure of 15CDV6 steel in quenched condition is predominantly lower bainite and a small portion of lath martensite[4]. 15CDV6 alloy steel lends itself remarkably well to all welding processes[5] oxyacetylene, electric arc, resistance, electron beam, and laser beam welding.

Welding can be carried out without the need for subsequent heat treatment and there is only negligible loss of properties during welding. High heat inputs should be avoided when welding 15CDV6 steels because these are usually associated with large weld beads which have a coarse, segregated structure and poor toughness. Assemblies with strength greater than 1000 Mpa can be obtained without any requirement for heat treatment [6-8].

Laser beam has a higher energy concentration. Since the heat input to the workpiece is extermely small during the Laser beam welding, the size of the heat-affected zone and the thermal damage to the adjacent parts of the weld are negligible. Laser beam welding is used largely in aerospace and electronic industries, where extreme control in weldments is required[9].

High-strength low-alloy steel exhibits its best properties of strength and toughness in heat-treated condition. In the present work, the parent material was subjected to the heat treatment and then laser beam welding was carried out. The microstructural evaluation in different regions of the welds and its relation with hardness, tensile strength, and impact properties was attempted. This study assumes significance as limited data are available on the similar welds of these steels.

2. EXPERIMENTAL DETAILS

The parent material employed in this study was high-strength low alloy steel in the form of 5.2 mm thick sheets. To evaluate the microstructure and mechanical properties of laser beam welds, initially the material was given respective heat treatment. The 15CDV6 steel plates were hardened by heating to 980 °C for 30 min. followed by air cooling, and then tempered by heating to 640 °C for 30 min followed by forced air cooling. The chemical composition of the high-strength low-alloy steel sheets in weight per cent are shown in Table 1.

Tentative welding parameters were arrested through the

Received 13 May 2015, revised 02 July 2015, online published 30 July 2015

Table 1. Chemical composition of high-strength low-alloy steel (15CDV6)[6]

Element	*Mn*	*Cr*	*Mo*	*V*	*C*	*Si*	*Fe*
15 CDV6	0.8-1.0	1.25 -1.5	0.8-1.0	0.2-0.3	0.12- 10.18	0.13	Balance

bead-on plate trials. Based on the feedback from the bead-on plate trials, sample plates (500 mm x150 mm x 3.7 mm) were welded with laser power-3.5 KW, and travel speed 2 mm/min. Welding was carried out along 500mm length to realise three tensile and three impact test specimens for each set of weldment in the longitudinal direction (direction of rolling). Specimens for metallography and hardness traverse were also obtained after discarding 15 mm - 20 mm from edge of the weld seam. After welding, the welded coupons were subjected to visual, dye penetrant, and radiography tests before sectioning it for different destructive tests.

Metallographic studies consisting of microstructural examination of the weld zone, HAZ and base material were carried out. The welds were subjected to standard metallographic sample preparation to examine the microstructure under optical microscope. B x 51 metallurgical microscope was employed. To reveal the microstructure, the low-alloy steel weld was etched using 2 per cent Nital (2 *ml* HNO_3 and 98 ml methanol).

As per ASTM-A-370, standard flat tensile testing specimens are machined with a width of 12.5 mm and 100 mm parallel length. The test was carried out using 10 ton machine equipped with hydraulic grips following a travel speed of 1 mm/min.

Microhardness survey was conducted across the welds beads at mid-thickness on cross section of all the welded coupons from the weld centre to parent material through heat-affected zone. employing a Vickers Micro hardness Tester (Future – Tech FM- 700). All of the hardness readings were obtained at 100 gf load for 15 s. Measurements were been done with 0.15 mm between consecutive indentations.

Impact toughness was estimated by a Charpy test in which a square sectioned, notched bar is fractured under given conditions and the energy absorbed in the process is taken as an empirical measure of toughness. For impact testing, standard sub-size specimens as per ASTM-A 370-12 were machined. The impact testing was carried out at room temperature.

3. RESULTS AND DISCUSSION

3.1 Microstructure

A view of the laser-beam welded joint of similar metal combination of high-strength low-alloy steel is shown in Fig. 1. In the as welded condition of 15CDV6 similar welds, there are five distinct regions in the weld and HAZ as labelled in Fig. 2.

Region A represents the unaffected parent metal during the welding, which exhibits a lower bainitic structure with feather like feature. Region C is the coarse HAZ region. During welding, the parent material adjacent to the weld interface is heated to a high temperature. If the cooling rate is slow, it transforms to bainitic structure and if the cooling rate is fast, it leads to martensite structure. Region B is the fine HAZ region. Region away from the fusion zone experiences lower peak temperature and the martensite decomposes into austenite,

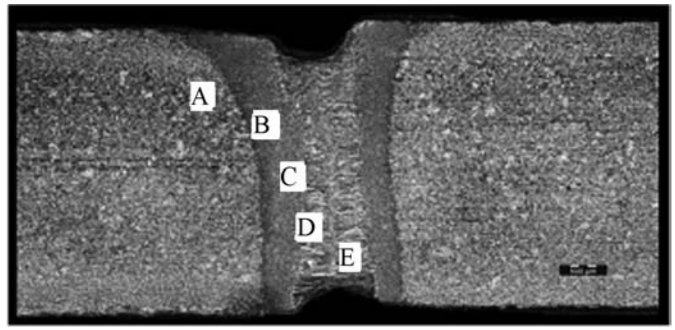

Figure 1. Laser beam welded joint of high strength low alloy steel.

ferrite and carbide constituents. Region D is the interface of the weld region to the coarse HAZ. Region E is the fusion zone. It shows a martensite structure with epitaxial grain growth.

3.2 Hardness

Prior to testing, weld specimen was prepared to have mirror finish, free from surface cracks to identify the clear vision of indentation. Microhardness measurement across the weld in the as welded condition shows four distinct regions as shown in Fig. 3. These regions are A-weld; B- Coarse-grained HAZ; C- fine HAZ, and D-unaffected parent metal. During welding as the different regions were exposed to various temperatures, the hardness also varies accordingly. The average weld metal hardness was 480 Hv. The weld zone exhibited higher hardness than HAZ and base material. The increased hardness in fusion zone may be due to the martensite. Due to the grain refinement occurred in HAZ, this region observed higher hardness than the base material[10]. The coarse HAZ region has lower hardness than the fine HAZ region.

3.3 Tensile Properties

The transverse tensile properties of the welds were evaluated. Table 2 shows the results of ultimate tensile strength, yield strength, and total elongation for the welds. The properties of the parent metal were also include for comparison purpose. The UTS, 0.2 per cent YS and per cent elongation in the as welded condition match with those of the parent metal in the 'as received condition'.

The fracture occurred away from the fusion boundary as shown in Fig. 4. This may be due to presence of low hardness region as a result of over tempering of this region due to exposure at high temperatures during the welding process.

Table 2. Transverse tensile properties of laser beam weld joint of 15CDV6 steel

Material condition	UTS (MPa)	0.2%YS (MPa)	% Elongation
As received	1080	970	12
As welded	1020	918	12

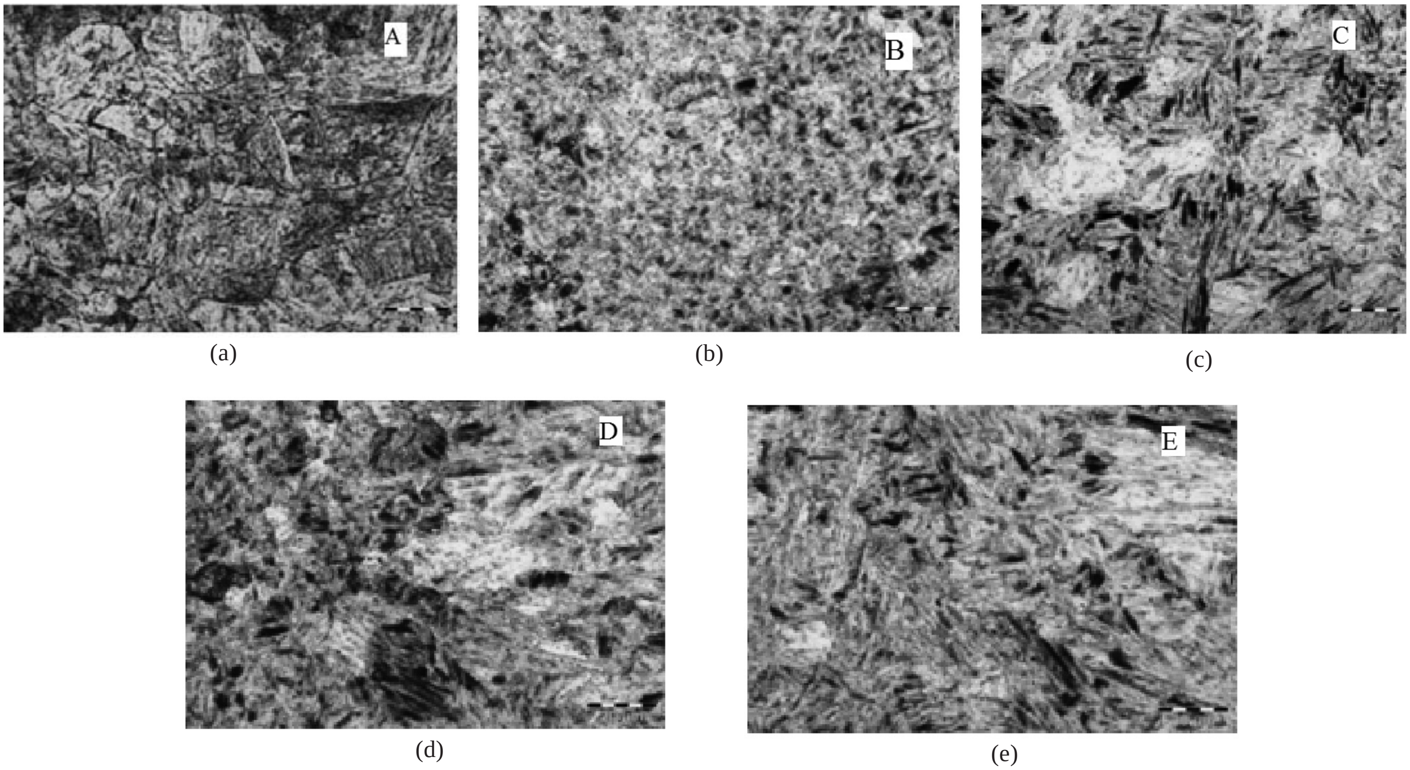

Figure 2. Optical microstructure of weld and HAZS in high-strength low-alloy steel: (a) Base material 15CDV6, (b) Fine HAZ, (c) Coarse HAZ, (d) Coarse to weld interface, and (e) Weld centre.

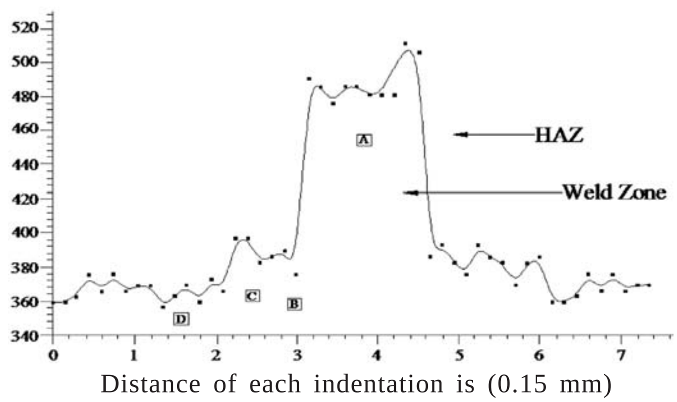

Figure 3. Hardness traverse across the weldment (as welded).

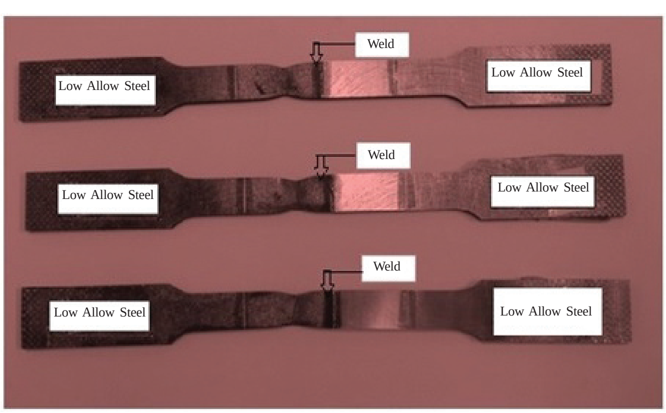

Figure 4. Photograph of welded transverse tensile specimen.

3.4 Impact Toughness

The impact toughness data of normalised sub-size specimens as per ASTM standard for laser beam welds of 15CDV6 steel is presented in Table 3. The parent metal data also presented for comparison.

The welds exhibited lower toughness data compared to parent metal. The low toughness of as welded 15CDV6 steel may be due to the presence of untempered martensite.

Table 3. Impact properties of laser beam weld joint of 15CDV6 steel

Material condition	Impact energy (J)	
As received	Parent metal	55
As welded	Weld metal	50

4. CONCLUSIONS

The following are the conclusions that arise out of the present study:

- The tensile strength values of the welded specimens were close to that obtained for parent sheet specimens, demonstrating that the alloy studied in this work is successfully welded by the CO_2 laser source.
- The fusion zone of the as welded 15CDV6 alloy steel exhibits a epitaxial grain growth.
- Similar metal welds of low-alloy steel consists of a cicular martensite near-fusion boundary and just away towards the base metal martensite, is seen to decompose into austenite, carbides, and ferrite constituents.
- The hardness distribution shows that the weld is having

maximum hardness and declining to the parent metal through the HAZ region.

- The as welded 15CDV6 steel exhibits lower toughness data compared to parent metal. Lower toughness of the weld may be due to the presence of untempered martensite.

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ACKNOWLEDGEMENTS

The authors would like to thank Dr Tessy Thomas, Director, ASL, Dr K. Jayaraman, Director, DRDL, and Mr J. Ram Mohan GM, SFC for the continuous encouragement and permission to publish this work. The support received from CLPM Group of ARCI, MDD Group of DRDL is duly acknowledged.

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In the current study V. Venkateswara Rao also supervised the research. All experimental work were carried out under his guidance also. The results was reviewed by him also.