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Research Paper

WELDING DEVELOPMENT IN ESR MODIFIED 15CDV6 MATERIAL

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The AFNOR 15CDV6 steel is high strength steel with relatively low level alloy content. By processing the steel through ESR with inoculation a marginal increase in strength and further increase in ductility and notch toughness can be obtained. The strength of the steel is inadequate for its use in fabrication of rocket motor casing in the Indian Space Programme. By increasing both carbon and chromium content of the AFNOR 15CDV6 steel strength can be increased, primarily as a cost effective for space launch vehicle applications. Welding is a major step in the fabrication of most of the pressure vessels, structures and equipments. Steels with carbon equivalent in excess of 0.40wt% shows a tendency to form martensite on welding, and therefore are considered difficult to weld. This ESR modified 15CDV6 material has a carbon equivalent value of nearly 1.0 that classified it as a very difficult to weld steel. In the present work, ESR modified 15CDV6 material welding was carried out successfully by Auto GTAW as well as Manual GTAW, without preheating. This was carried out by modification of welding parameters, cleaning process, tacking sequence etc. Mechanical Properties of the Weld are meeting requirements.

Keywords: AFNOR 15CDV6, ESR, GTAW, Chromium, Molybdenum, Vanadium, Bainitic steel

INTRODCUTION

AFNOR 15CDV6

The AFNOR 15CDV6 steel is high strength steel with relatively low alloy content. The incipient development took place in France. This Ultra high strength steels are becoming increasingly important in aerospace, defence, power generation and in other applications industries. Because of its good strength-ductility combination and ease of fabrication the material has been extensively used in rocket-motor hardware in the Indian Space Programme.

Due to the characteristics of Chromium and Molybdenum, compatibility with high hardenability and high strength emphasizes.

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Vanadium plays vital role in controlling grain coarsening and with the addition of certain inoculants mechanical properties like strength and ductility increases effectively.

Metallurgical Aspects in AFNOR 15CDV6

The steel AFNOR 15CDV6 is a high strength bainitic steel containing low concentrations of chromium, molybdenum and vanadium as alloying elements. The micro structure of 15CDV6 steel in quenched condition consists of predominantly lower bainite and a small proportion of lath martensite.

Earlier attempts to improve the properties of this steel through Electro Slag Remelting (ESR) resulted in large increase in ductility and toughness with little or no increase in strength. A small increase in strength and further increase in ductility and notch toughness were obtained by inoculating the steel with 0.2% addition of niobium or zirconium during ESR.

A recent study has reported that strength of mixed microstructure containing tempered martensite and bainite can peak at an intermediate volume fraction of tempered martensite of around 0.75. Increase fraction of martensite in a mixed martensite-bainite microstructure can be achieved by the addition of alloying elements, which retard the bainite reaction.

Alloying elements, particularly carbide forming elements, greatly retard the ferrite-perlite reaction and chromium, in particular, is very effective in retarding the bainite reaction. This often results in a bay of high relative austenite metastability being formed between ferrite-pearlite and bainite reaction whilst moving the whole TTT diagram to longer time.

In view of the effectiveness of chromium in retarding the bainite reaction, it was expected that increasing the chromium content in modified 15CDV6 steel would lead to increase in strength. Moreover addition of chromium up to 6% can also retard softening upon tempering. Accordingly, chromium content in the modified 15CDV6 steel was increased from 1.5 to 4%.

As the strength level of steel increases, the defect tolerance level decreases. Therefore, a high degree of chemical and structural homogeneity and freedom from inclusions becomes important for ultra high strength steels. For this reason, subjecting steel to remelting process such as ESR becomes necessity.

Promoting heterogeneous nucleation during solidification by inoculation technique refines the grain size and thereby results in improvement of strength and ductility. For homogenous nucleation low contact angle with substrate and minimum misfit of lattice is required.

Yield strength for ESR Modified 15CDV6 steel (0.26C, 4cr, 0.68 Mo), i.e., 1400-1420 Mpa is almost 40% higher than yield strength of the Ti-inoculated ESR standard 15CDV6 steel (0.15 c, 1.50 Cr.0.8 Mo), i.e., 990-1020 MPa.

Inoculation with titanium during ESR can significantly reduce the grain size resulting in improvement in mechanical properties of the steel. The increase in toughness and ductility with increase in strength at higher chromium and carbon contents. This due to precipitation of very fine uniformly dispersed chromium carbide particles, which resists the crack propagation.

EXPERIMENTAL WORK

Welding Development Activities

Welding is a major step in the fabrication of most of the pressure vessels, structures and equipments. Steels with carbon equivalent in excess of 0.4wt% shows a tendency to form martensite on welding, and therefore are considered difficult to weld. ESR Modified 15CDV6 has a carbon equivalent value of nearly 1.0wt%, that classifies a very difficult to weld steel.

From weldability point of view, it's very difficult to weld, this exhibits as follows by Carbon Equivalent (CE).

$$CE = \%C + \frac{(\%Mn + \%Si)}{6} + \frac{(\%Cr + \%Mo + \%V)}{5} + \frac{(\%Cu + \%Ni)}{15}$$

If $CE > 0.40$ prone to cracking tendency in HAZ.

Initial trials were carried out to establish the welding parameters for Welding Procedure Specification (WPS) activity. Although, without pre-heating it was difficult to weld the plates, but trials were taken and found successful.

Plate size used: 500 mm (*L*) x 150 mm (*W*) x 7.8 mm (thick)

For WPS qualification it was necessary to weld continuously 10 weld coupons. After Welding Heat treatment and subsequently Mechanical testing activity was carried.

Parameter Settings: Welding parameter settings took place, by welding almost 9-10 plates. Preliminarily problem faced like penetration issues, porosities, LF, etc. which was overcome after taking proper action. By this Phase-0 was completed.

For Phase-I further WPS activity was carried out by welding continuously 10 weld coupons by Automatic GTAW process. Radiography and UT Test were satisfactory.

HEAT TREATMENT

In addition of niobium content of about 0.10% and vanadium content of 0.25% this has deleterious effect on the toughness properties of low carbon welds, because of this ESR modified 15CDV6 Welded Plates were taken for heat treatment activities, i.e., welding followed by hardening and tempering Heat treatments.

Table 1: Heat Treatment Cycle

Process	Temperature	Time	Quench Medium
Hardening			
Loading	< 600 °C	–	–
Hardening	920 + 10 °C	1 hour	water
Quench Delay	–	< 45 sec	–
Stress Reliving: To be carried out within 2 hrs of hardening			
Loading	< 200 °C	–	–
Stress Relieving	300 + 10 °C	1 hour	Air
Tempering			
Loading	< 300 °C	–	–
Tempering	505 + 5 °C	2 hour	water
Quench Delay	–	< 45 sec	–

Note: The Heating rate shall not be more than 100 °C/hour).

WELDING PROCEDURE SPECIFICATION

Welding Procedure Specification Qualification includes following documentation:

1. Weld Data sheets
2. Radiographic Test report
3. Ultrasonic Test report

4. Heat treatment details
5. Transverse Tensile Test report
6. Fracture Toughness Test reports

RESULTS AND DISCUSSION

The welding of ESR Modified 15CDV6 Plates by Automatic GTAW process without preheating, was difficult because of Carbon Equivalent (C E) > 0.9. As increasing carbon and chromium content in this steel, there has been an increasing amount of martensite in the mixed microstructure of martensite-bainite being (0.26 C, 4.0 Cr and 0.68 Mo) as compared to the microstructure of standard 15CDV6 steel (0.15 C, 1.5 Cr, 0.9 Mo), consisting predominantly bainite.

Parameter Setting: By giving sufficient trials and by modifying root gap and current combination it was possible to set the welding parameters.

Table 2: Root Gap Requirements for Various Mechanical Tests

S. No.	Properties	Requirement
1.	Ultimate Strength (UTS), MPa	1375 (min.)
2.	0.2% Proof Strength (UTS), MPa	1275 (min.)
3.	Elongation (%)	–
4.	Fracture Toughness [as per ASTM E-399], MPa√m	75 (min.)

Table 3: Mechanical Testing Requirement for ESR Modified 15CDV6 Welds

S.NO	PLATE ID	RT	UT	TT	UTS (Mpa)	PS (Mpa)
1	TP 19	ok	ok	TT3	1378	1337
2	TP 20	ok	ok	TT2	1379	1211
				TT3	1366	1334
3	TP 21	ok	ok	TT1	1383	1257
				TT2	1381	1299
				TT3	1370	1301
4	TP22	ok	ok	TT3	1376	1276
5	TP23	ok	ok	TT1	1366	1328
				TT2	1364	1312
				TT3	1380	1300
6	TP24	ok	ok	TT1	1372	1277
				TT2	1395	1312
				TT3	1353	1278
7	TP25	ok	ok	TT1	1383	1303
				TT2	1385	1278
				TT3	1376	1276
8	TP26	ok	ok	TT2	1386	1288
				TT3	1376	1318
9	TP27	ok	ok	TT1	1384	1290
				TT2	1375	1292
10	TP28	ok	ok	TT1	1387	1251
				TT2	1376	1299
				TT3	1368	1334

WI JOB No - 78371
Consolidated Tensile Test Results - ESR Modified 15CDV6 (Water Quenched)

Table 3 (Cont.)

S.NO	PLATE ID	RT	UT	TT	UTS (Mpa)	PS (Mpa)
1	TP 19	OK	OK	TT2	1569	1527
				TT3	1461	1380
2	TP 20	OK	OK	TT1	1467	1421
				TT2	1472	1405
				TT3	1470	1435
3	TP 21	OK	OK	TT1	1464	1462
				TT3	1442	1432
4	TP 22	OK	OK	TT1	1465	1445
				TT2	1469	1428
5	TP 23	OK	OK	TT1	1449	1417
				TT2	1456	1437
				TT3	1461	1420
6	TP 24	OK	OK	TT2	1480	1455
				TT3	1480	1442
7	TP 25	OK	OK	TT1	1474	1431
				TT2	1480	1426
				TT3	1473	1398
8	TP 26	OK	OK	TT1	1467	1434
				TT2	1480	1408
				TT3	1474	1429
9	TP 27	OK	OK	TT1	1482	1466
				TT2	1472	1399
				TT3	1486	1447
10	TP 30	OK	OK	TT1	1480	1458
				TT3	1477	1418
WI JOB No - 78371 Consolidated Results of Test Plates - ESR Modified 15CDV6 (Water Quenched)						

Table 4: Strength Specifications for Various Quench Medium

Type	UTS Value Min.	UTS Value Max.	0.2 PSMin.	0.2 PSMax.	Remark
Water Quenched Specimens	1366 MPa	1395 MPa	1251 MPa	1337 MPa	UTS meeting requirement = 69% 0.2 PS meeting requirement = 87%
Oil Quenched Specimens	1442 MPa	1569 MPa	1380 MPa	1527 MPa	UTS meeting requirement = 100% 0.2 PS meeting requirement = 100%

Initial Problems

Porosities: porosities were observed in initial trials, but later on by proper cleaning methodology it was eliminated. Wire cleaning by means of scrapper and followed by three times wire cleaning with acetone was carried out. Entire welding carried out in clean dust free hall, by taking extra precautions not to get any contamination.

After welding of 10 nos of Coupon plates following tests were carried out:

Visual Examination: The weld was free from visual defects like Lack of Fusion, Undercuts, excess penetration, visual pores, etc.

Dye Penetrant Test: No DP indication observed on weld.

Radiographic Test and Ultrasonic Test: No Radiographic defects and NO UT defects observed in the weld. Weld was absolutely sound.

Mechanical Testing: Transverse Tensile test and Fracture Test carried out on Heat treated Weld specimen.

CONCLUSION

- ESR Modified 15CDV6 Welding by Auto GTAW process can be possible by proper parameter setting and precautions without preheating technique.
- Oil Quenching Treatment to the Weld Coupon gives success rate 100% than the Water Quenched Weld Coupon. Improvement in mechanical properties as compared to Water Quenching treatment.
- Oil Quenched Weld Coupon gives 12.4% more UTS and 14% (maximum) more 0.2 PS value than Water Quenched Weld Coupon.
- Not much improvement in % elongation observed either by Water Quenching or by Oil quenching.

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