Nano World Journal

https://doi.org/10.17756/nwj.2023-s4-021

Research Article

Open Access

Effect of Heat Treatment Soaking Time on Mechanical Properties of 15CDV6 Steel

Yogeswara Rao Dunga* **and Indira Rani Marpu**

Department of Mechanical Engineering, Jawaharlal Nehru Technological University, Hyderabad, Telangana, India

***Correspondence to:**
Yogeswara Rao Dunga
Department of Mechanical Engineering,
Jawaharlal Nehru Technological University,
Hyderabad, Telangana, India.
E-mail: yogeshdunga@gmail.com

Received: September 15, 2023
Accepted: November 21, 2023
Published: November 24, 2023

Citation: Dunga YR, Marpu IR. 2023. Effect of Heat Treatment Soaking Time on Mechanical Properties of 15CDV6 Steel. *NanoWorld J* 9(S4): S119-S122.

Published by United Scientific Group

Abstract

AFNOR 15CDV6 is heat treatable high strength low alloys (HSLA) material and is widely being used in solid rocket motor cases manufacturing due to its high specific strength and weldability in both annealed and heat treated conditions. Present study is made to find out the impact of soaking time in hardening and tempering treatment on the mechanical properties of 15CDV6 material. Two forging specimens with different effective thicknesses 110 mm and 40 mm are used for this purpose. Hardening and tempering is carried out for these two specimens together with the soaking time applicable to 110 mm thickness. In this case, the 40 mm thick specimen is subjected to over soaking. Electrically heating furnace is used for this purpose. First hardening is carried out at 810 °C and second hardening is carried out at 930 °C followed by tempering at 610 °C. In all heat treatment cycles, quench medium is water. Hardness test, tensile test are carried out as performance characteristics and the test results are compared for both the specimens. The metallurgical characteristics of both the specimens are discussed briefly. The Charpy impact test is conducted for the 40 mm effective thickness specimen.

Keywords

15CDV6, Effective thickness, Hardening, Tempering, Charpy impact

Introduction

15CDV6 is a low carbon alloy steel with very good yield strength. It also has very good toughness and excellent weldability. 15CDV6 is a French designation where in which the letters ‘C’ stands for Chromium, ‘D’ stands for molybdenum and ‘V’ stands for Vanadium [1]. The numbers 15 indicate nearly 100 times of the carbon percentage and 6 indicates nearly 4 times percentage of Chromium. Manganese (Mn), phosphorous (P), silicon (Si) and sulfur (S) contains a small percentages and the total alloy proportion is less than 5%. This is largely being used in solid rocket motor cases and some separation systems of Indian space research applications. This material possesses good combination of strength to weight ratio and ductility and excellent weldability [1, 2]. This material shows similar properties in welding followed by heat treatment as well as heat treatment followed by welding [3].

An effective thickness in 15CDV6 material is very critical parameter in heating and quenching processes. The process of any heat treatment consists of heating, holding at a particular temperature, called as soaking and cooling. Annealed condition 15CDV6 forgings attain their strength by double hardening at 810 °C and 930 °C and oil or water quenching followed by tempering at 630 °C and oil or water quenching. Water is a preferred quench medium for higher thicknesses considering the safety conditions. Oil quench has the tendency of catch fire. Soaking time is the time required to reach the entire volume to austenizing temperature. The yield strength, tensile strength, hardness and impact strength decreases with increase in soaking time [4].

The mechanical properties viz. ultimate tensile strength (UTS) and the hardness of the steels are decreases with the rise in tempering temperature [5]. The microstructure of 15CDV6 steel (0.15 C, 1.5 Cr, and 0.9 Mo) after quenching consists predominantly bainite structure [6, 7]. The precipitated carbides namely Mo_2C, VC in the bainitic structure of 15CDV6 causes the secondary hardening effect in the material [1], while increasing the tempering temperature up to 650 °C. This causes increase in strength and hardness. The % elongation and Charpy U-notch toughness will increase with reduction in grain size [8, 9].

15CDV6 material also shows good welding characteristics in Powdered Flux Tungsten Inert Gas welding using nano powders like NiO [10]. The carbides nano scale size in HSLA steels gives additional yield strength to the material [11]. No literature is available for this material regarding the effect of heat treatment soaking time on the properties achieved when two different effective thicknesses specimens are heat treated together.

In this study, an attempt is made to find out the impact of soaking time of heat treatment on the mechanical properties achieved by considering two different effective thickness specimens. These two specimens are hardened and tempered together with water as quench medium. The mechanical, microstructure and Charpy impact strength properties are evaluated and compared for both the specimens.

Experimentation

15CDV6 forgings in annealed condition are used in this study. Two test pieces of sizes 200 x 100 x 110 mm and 200 x 100 x 40 mm are machined from the same batch of forging. Chemical composition of the forging is as shown in table 1. Table 2 shows mechanical properties of the forging in hardened and tempered condition with soaking time of 4 min/mm of effective thickness in first and second hardening and soaking time of 8 min/mm of effective thickness for tempering.

Table 1: Chemical composition of the forging.

Alloying element	C	Cr	Mo	V	P	S	Mn	Si	Fe
Composition (Wt.%)	0.18	1.45	0.88	0.22	0.008	0.007	0.92	0.2	Balance

Table 2: Mechanical properties of the forging in hardened and tempered condition.

Ultimate tensile strength	(MPa)	1030 - 1120
0.2% proof stress	(MPa)	952 - 1016
Elongation	(%)	18 - 20
Hardness	(BHN)	320 - 350
Impact strength	(J/cm^2)	136 - 160

Table 3: Heat treatment cycle followed for the test specimens.

Process	Temperature (°C)		Soaking time (min)	Quench medium	Quench delay (s)
	Loading	Soaking			
First hardening	400	810	440	Water	37
Second hardening	450	930	440	Water	38
Tempering	480	630	880	Water	37

Bogie type electrical heating furnace having kanthal heating element, refractory brick walls and bed and centralized fan for forced circulation is used for heat treatment. Both the coupons are heat treated and quenched together. The heat treatment process involved is shown in table 3. First hardening is carried out at 810 °C for soaking time of 440 min. This is followed by quenching in water maintained at room temperature. Second hardening is carried out at 930 °C for soaking time of 440 min. This is followed by quenching in water maintained at room temperature. Tempering at 630 °C is followed for soaking time of 880 min and quenching in water maintained at room temperature. In all three cycles, the loading temperature is less than 500 °C and the rate of heating is less than 100 °C per hour. Quench delay is maintained at less than 40 s in hardening and tempering cycles.

Heat treatment cycle is selected to ensure 100% austenite formation in 110 mm effective thickness test piece. In 40 mm test piece, the soaking duration is much higher and hence this test piece experienced over soaking. Test pieces are taken out from the quench bath after 30 min. Temperature of quench water is recorded before and after quenching. Increase of water temperature is 15 °C.

From the two test pieces, three tensile test specimens are machined from the core as per ASTM A 370 as shown in figure 1. Three impact test samples are machined from each test piece for Charpy impact test as per ASTM E 23. The 'U' shape notch specimens are made for the impact test with size 10 x 10 x 55 mm and notch depth 5 mm. Macro specimen examinations is done on the specimens and the rating is C1 S1 R1. The specimens for microstructure are taken from the core of both the test pieces. Specimens are polished and etched and the metallurgical examination is carried out using MET SCOPE-1 microscope. Both samples have shown the bainitic microstructure with grain size ASTM 7.5 as shown in figure 2.

Results and Discussion

The practice being followed for aerospace applications for heat treating the 15CDV6 forging is keeping the soaking time at 4 min/mm of effective thickness in first and second hardening

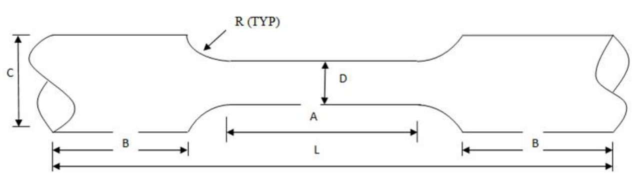

Figure 1: Tensile test specimen. D: Reduced cross section diameter - 8.75 mm, A: Reduced cross section length - 55 mm, R: Radius - 8 mm, C: Gripping diameter - 12 mm, B: Gripping length - 60 mm, and L: Overall length -185 mm.

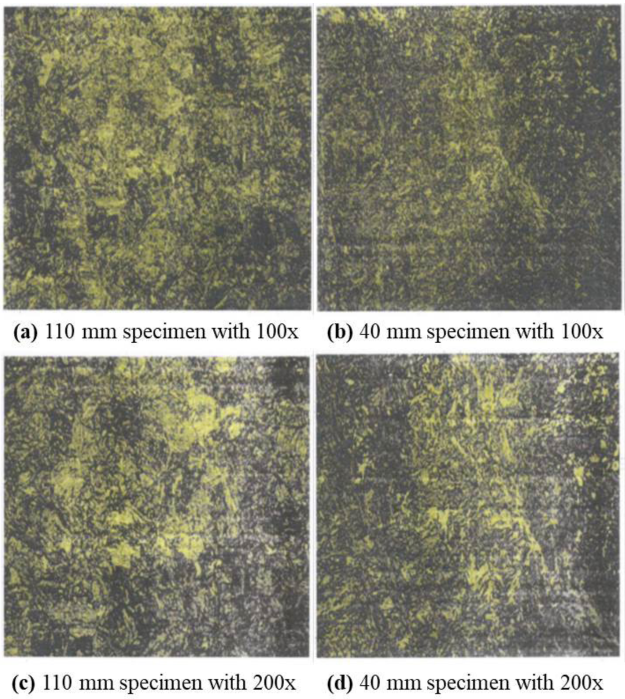

Figure 2: Microstructure from the core of the test samples.

and at 8 min/mm of effective thickness in tempering cycles, i.e., the soaking time is dependent on the effective thickness of the component to be heat treated. The effective thickness of any component is defined as the maximum circle which can be inscribed in to the cross section of the component.

Hardness is measured on two specimens as 321 to 341 BHN using Brinells hardness testing machine. The tensile samples are tested in a Universal Testing Machine of FIE model with 20 ton capacity for UTS, 0.2% proof stress, and % elongation on 4D gauge length.

Gauge length, 4 x D = 35 mm; where D - Reduction length diameter of the tensile specimen. The obtained mechanical properties of the hardened and tempered specimens from both the test pieces are mentioned in table 4. Three test samples (T1, T2, and T3) are CNC machined from each specimen for tensile test and Charpy impact test, i.e., for 110 mm thick specimen, 3 tensile samples and 3 Charpy U-notch samples and similarly for 40 mm thick specimen, 3 tensile samples and 3 Charpy U-notch samples.

A comparison of these values for both specimens is presented in figure 3. Separate graph for UTS (MPa), 0.2% proof stress, % elongation, and Charpy U-notch impact test results

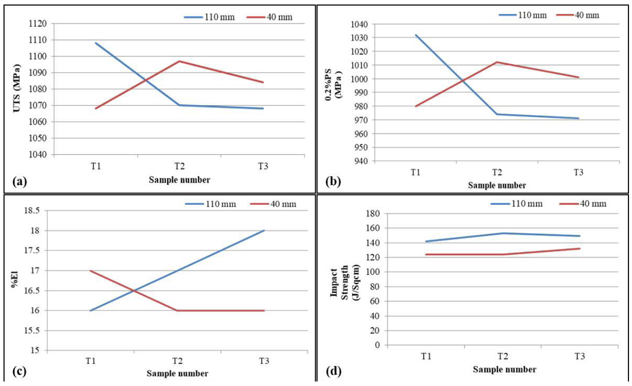

Figure 3: Comparison of **(a)** UTS, **(b)** 0.2% proof stress, **(c)** % elongation , and **(d)** impact strength values for the two specimens.

are made and compared these individual values for both the specimens.

In this study, two specimens of different effective thicknesses (110 and 40 mm) are heat treated together following the heat-treatment cycle applicable for 110 mm thickness. Mechanical properties achieved are very close for both the test specimens as shown in figure 3a to figure3d. Both the specimen properties are meeting the material property specification. The impact strength values are shown in figure 3d in which the 40 mm thick specimen is showing slightly lesser impact strength than 110 mm specimen. This could be due to the over soaking effect of 40 mm coupon as the soaking time given is according to 110 mm coupon.

The macrostructure examination is carried out and it is showing C1 S1 R1 rating as per ASTM E 381-01 for both the specimens. The microstructure shows bainite structure in both the test specimens. It is reported that 15CDV6 steel forms bainite over a wide range of cooling rates especially in thicker section and martensite formation is limited to very thin section [9]. In the present test specimens, it is also seen that the grain sizes are similar. These two are the reasons for matching properties of both the specimens. Apparently, this analysis gives the flexibility of combining different effective thicknesses material in to the same batch of heat treatment.

Conclusions

The effect of heat treatment soaking time on mechanical properties of 15CDV6 steel specimens with different effective thicknesses (110 and 40 mm) heat treated together is experimentally investigated. The observations are as follows:

Table 4: Mechanical properties observed on test specimens in hardened and tempered condition.

Specimen thickness	Test sample	Ultimate tensile strength (MPa)	0.2% proof stress (MPa)	Elongation (%)	Impact strength (J/cm²)
110 mm	T1	1108	1032	16	142
	T2	1070	974	17	153
	T3	1068	971	18	149
40 mm	T1	1068	980	17	124
	T2	1097	1012	16	124
	T3	1084	1001	16	132

- It is found that the tensile test results viz. UTS, 0.2% proof stress and % elongation for both the specimens are meeting the material's specification.
- The microstructure of the samples taken from core of both the specimens contains the bainite structure. The grain sizes for both the specimens are same as ASTM 7.5
- The macrostructure of both the specimens shows C1 S1 R1 rating.
- But the impact strength values for 40 mm thick specimen are slightly less than 110 mm thick specimen, this is attributed to over soaking of 40 mm specimen as the soaking time given is applicable to 110 mm thick.

From the above observations, it is understood that though the specimens having different effective thickness they are showing similar properties due to their similarity in microstructure and grain sizes. So, 15CDV6 forgings of effective thickness variation of 70 mm can successfully be hardened and tempered together with water quenching.

Future Scope of Study

The scope of this study is limited to estimate the effect of heat treatment soaking for the effective thickness variation of 70 mm. The same test can be verified for a larger difference of effective thicknesses to ensure the similar properties and study can be extended for plates also with different thicknesses.

Acknowledgements

None.

Conflict of Interest

None.

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