Effect of duration of deep cryogenic treatment on microstructure and tensile properties of 1.2542 tool steel

S.E. Vahdat[1]* S. Nategh[2]
Sh. Mirdamai Tehrani[3]

1. Introduction

Successful employment of advanced tool steel in engineering applications relies on its ability to meet service life requirements and to be fabricated with proper dimensions. This means toughness (U_T), strength and hardness must increase simultaneously. In the last decades, many researchers have reported that subzero treatment of metals could fulfill the need for producing high ultimate tensile strength (UTS) and wear resistant tool steels for engineering applications at lower cost. Deep cryogenic treatment (DCT) could improve hardness, UTS and toughness simultaneously. The first mechanism of precipitation of secondary carbide (SC) is due to the expansion resulting from transformation of the retained austenite into martensite and secondly caused by the difference in thermal contraction of the phases. For this reason, the goal of this work was to optimize the duration of DCT to produce advanced 1.2542 tool steel.

2. Material and Methods

The specimens were given codes for easy identification as following:

(a) Water quenched specimens: The first two digits of the code for a specimen indicate the soaking time (h) at -196ºC. The last digit indicates the tempering time (h) at 200ºC (Figure 1).

(b) Oil quenched and tempered at 450ºC: The specimen coded as standard specimen.

(c) Water quenched and tempered specimens (non-DCT): Specimens 002 and 003 have been tempered at 200ºC, but no DCT has been performed on these specimens (Figure 1).

3. Results and Discussion

Results of tensile tests and modulus of toughness, and microstructure results are listed in Table 1, 2 and 3, respectively. tempering after conventional treatment. In other words, increasing DCT duration produced more defects and more defects needed increasing tempering time (at constant tempering temperature) to obtain high modulus of toughness.

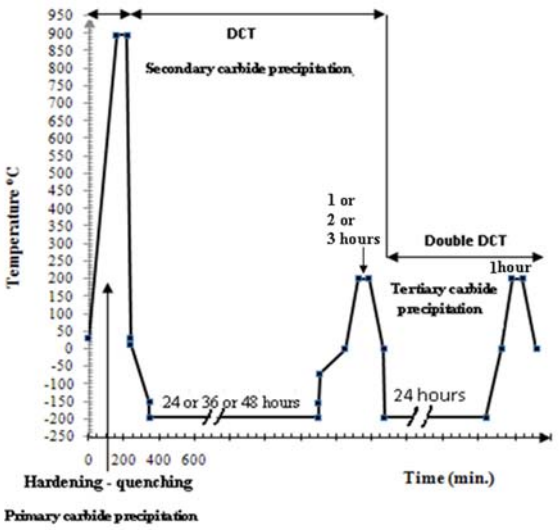

Figure 1: DCT and double DCT Cycles

[1] *Corresponding Author, Assistant Professor, Department of Engineering, Ayatollah Amoli Branch, Islamic Azad University, Amol, Iran.
Email: e.vahdat@iauamol.ac.ir

[2] Professor, Department of Materials Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran.

[3] Professor, School of Metallurgy and Materials Engineering, Iran University of Science and Technology, Tehran, Iran.

hardness of the DCT specimens showed 32-36% and 9-12% increase, respectively, because the standard specimen stipulated quenching in oil and tempering at 450ºC while DCT treated specimens were quenched in water prior to their DCT. This issue provided effects of this treatment cycle on the advanced 1.2542 yield strength, UTS and hardness.

Table 1 reveals that under similar conditions, changes in the UTS and yield strength followed a similar trend as expected.

In this research, specimens 361 and 482 had higher modulus of toughness than conventionally treated ones, which showed that increasing DCT duration needed increasing tempering time to obtain high modulus of toughness. For example, for 36 hours of soaking time at -196ºC, 1 hour tempering time was needed to obtain maximum modulus of toughness. For 48 hours soaking time at -196ºC, the corresponding tempering time was 2 hours. This means that, with increase in the tempering time, longer soaking time was required for obtaining maximum modulus of toughness because tempering after DCT caused more reduction of residual stress in comparison with As shown in Table 2, volume fraction of the PC was approximately constant (≈0.4±0.2 vol.%) in different specimens while Tables 2 demonstrated that volume fraction of the SC increased with soaking or tempering times from 2.18 vol.% to 12.87 vol.%. As shown in Table 2, an increase in soaking time resulted in precipitation of more SC (average, 500%) due to defect density around the PCs in phase matrix, which increased with an increase in the soaking time and facilitated precipitation of the SC.

Also shown in Table 2, an increase in tempering time resulted in a little precipitation of SC (average, 50%). On the other hand, volume fraction of SC in specimens 002 and 003 were somehow fixed since, without carrying out DCT, the conditions for the formation of SC were not facilitated.

Table 1 Results of tensile tests and modulus of toughness

Specimen code	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Hardness (RC)	Modulus of toughness (MJ/m^3)±0.65
standard	1525 ±50	1670 ±65	8.2 ±1.5	50 ±1.0	91.3
002	2006 ±50	2229 ±65	5.5 ±1.5	56.5 ±0.6	81.7
003	1938±50	2181 ±65	6.5 ±1.5	57.2 ±0.7	94.5
241	2007 ±15	2279 ±21	4.75 ±0.75	56 ±0.3	72.2
242	2019 ±23	2265 ±31	2 ±1.0	56 ±0.5	30.2
243	1869 ±49	2137 ±53	6 ±1.5	57.9 ±0.5	85.5
361	1990 ±50	2268 ±65	7 ±1.5	54.6 ±0.5	105.9
362	1945 ±50	2201 ±65	5 ±1.5	56 ±0.5	73.4
363	2003 ±50	2245 ±65	5 ±1.5	54.5 ±0.5	74.8
481	1972 ±44	2244 ±64	6.2 ±0.3	56.3 ±0.6	92.8
482	1943 ±50	2206 ±65	7.5 ±1.5	56 ±0.4	110.3
483	1996 ±18	2249 ±28	6.2 ±0.8	55 ±0.5	93.0

Table 2 Content, size, population density (PD) of SC and primary carbide (PC)

Specimen code	PC content ±50% (vol.%)	SC content ±10% (vol.%)	PC size (min to max) (µm)	SC size (min to max) (µm)	PD of PC (mm^{-2}) ±5%	PD of SC (mm^{-2}) ±2%
standard	0.10	1.90	0.6 (0.4to0.9)	0.17 (0.1to0.5)	20000	320000
002	0.42	1.80	0.61 (0.3to1.5)	0.35 (0.13to0.5)	64000	200000
003	0.40	1.88	0.65 (0.3to1.5)	0.4 (0. 13to0.5)	63000	160000
241	0.42	2.18	0.52 (0.3to1)	0.22 (0.065to0.5)	62000	660000
242	0.47	2.42	0.55 (0.3to1)	0.24 (0.065to0.5)	65000	630000
243	0.37	3.73	0.70 (0.6to0.9)	0.25 (0.065to0.7)	60000	600000
361	0.57	4.69	0.65 (0.5to0.8)	0.30 (0.065to1)	64000	894000
362	0.60	6.92	0.71 (0.4to1.7)	0.32 (0.065to0.7)	63000	750000
363	0.34	8.91	0.72 (0.4to1.5)	0.33 (0.065to0.6)	62000	726000
481	0.35	10.04	0.72 (0.3to1.4)	0.44 (0.065to0.7)	65000	707000
482	0.25	12.66	0.71 (0.4to1.4)	0.45 (0.065to1)	62000	650000
483	0.24	12.87	0.73 (0.4to2)	0.46 (0.065to1)	65000	620000

Table 3 Content of tertiary carbide (TC)

Specimen code	Content of SC+PC vol.% ± 5%	Content of TC vol.%±5%
002-241	2.8	1
003-241	2.8	0.92
241-241	3.1	0.92
242-241	3.2	0.78
243-241	4.4	0.67
361-241	5.3	0.61
362-241	7.4	0.48
363-241	9.3	0.39
481-241	10.3	0.26
482-241	12.9	0.24
483-241	13	0.13

As shown in Table 1, for different specimens, yield strength and UTS showed no relative change. However, when compared with the standard specimen, UTS and

There was no retained austenite in the specimens; however, PCs and SCs were present in these specimens. These carbides could play the role of second phase in the matrix. To verify second precipitation mechanism of the SC, the specimens again were immersed at -196^{o}C for 24 hours, after which they were tempered at 200^{o}C for 1 h. Henceforth, this process is called double DCT. For the second precipitation mechanism to be valid, TC should precipitate as the consequence of double DCT. It was observed that volume fraction of the SC increased compared to the value before the double DCT (Table 3). PD (and volume fraction) of the TC could be obtained by subtraction of the PD (and volume fraction) of the SC before and after double DCT (Tables 2 and 3). For example, for specimen 241, volume fraction of the SC before double DCT was found as 2.18 vol.% and, after the double DCT, it was increased to 3.10 vol.%, which meant volume fraction of the TC was 0.92 vol.%. Combining these results and considering the fact that volume fraction of SC particles increased with the double DCT (Tables 2 and 3), the second mechanism was verified for precipitation of the SCs.

4. Conclusions

Different soaking and tempering times were considered to study effect of various treatment cycles on mechanical properties and microstructure of advanced 1.2542 specimens.

1) Simultaneous improvement in hardness, UTS and modulus of toughness was obtained for specimens 361 and 482.
2) For advanced 1.2542, it was observed that maximum modulus of toughness could be obtained by simultaneously increasing soaking and tempering times. However, if reduction in production time and cost was of primary concern, lower soaking and tempering times would seem to be a more feasible option. In this case, specimen 361 would be a more feasible option.
3) DCT could improve modulus of toughness because pull-out of high PD of SCs occurred. In these specimens, high PD and increased volume fraction of SCs were two effective parameters for modulus of toughness enhancement.
4) Maximum hardness can be obtained either by increasing soaking or tempering times. However, if the reduction in production time and cost was of primary concern, increase in the tempering time would seem to be a more feasible option. In this case, specimen 243 would be a more feasible option.
5) The regions which facilitated formation of more SCs were developed so that the increased soaking time led to constant increase of volume fraction of

SCs; however, PD of SCs increased until 36 hours of soaking time while being reduced after this period.

6) Precipitation of the SC was primarily due to the expansion resulting from transformation of the retained austenite into martensite and secondly caused by the difference in thermal contraction of the phases.