Archives of Materials Science and Engineering

Volume 31
Issue 2
June 2008
Pages 87-90

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

Effect of retained austenite on the fracture toughness of tempered tool steel

A. Kokosza*, J. Pacyna
Faculty of Metals Engineering and Industrial Computer Science, AGH University of Science and Technology, ul. Mickiewicza 30, 30-059 Kraków, Poland
* Corresponding author: E-mail address: akokosza@uci.agh.edu.pl

Received 25.03.2008; published in revised form 01.06.2008

ABSTRACT

Purpose: This paper is an attempt of reviewing the outlooks about the favourable influence of retained austenite on fracture toughness of tool steels according to results of investigation concerning relations between tempering temperature, hardness, fraction of retained austenite and fracture toughness.

Design/methodology/approach: The tests were performed on the samples made of the 70MnCrMoV9-2-4-2 steel in which the fraction of retained austenite was changed by cold treatment and by changing the tempering temperature. On the ground of analysis of dependencies between fraction of retained austenite, hardness, fracture toughness and tempering temperature of hardened 70MnCrMoV9-2-4-2 steel the influence of retained austenite on fracture toughness of tested steel was investigated.

Findings: was found that retained austenite remaining in the structure of tested steel after quenching increased its fracture toughness on directly proportional way to its volume fraction. Advantageous influence of this phase was also found after tempering tested steel.

Research limitations/implications: It was pointed out that most beneficial influence of retained austenite exists when tested steel after hardening is low-tempered. At that moment the highest stabilization of the phase occurs. While at tempering temperatures above 220°C it was indicated that it is possible to combine retained austenite transition and irreversible tempering brittleness.

Originality/value: On the basis of own research, the authors present their own, original point of view on the issue of presence of retained austenite in the structure, its stability and the influence on fracture toughness of low-tempered tools steel.

Keywords: Tool materials; Fracture toughness; Retained austenite

PROPERTIES

1. Introduction

On the basis of data presents in work [1] one may assume that in the process of steel cracking one of the most important factors is level stabilization of retained austenite.

According to authors of paper [2, 3] thermal instability of this phase and, as its consequence, easy disintegration to α phase and carbides during tempering may lead to creation of cementite layer on the boundaries between austenite and martensite lath, making brittle cracking easier.

Also one may not rule out that there was occurring, due to intensity increase of applied stress, a mechanical destabilization of austenite what additionally would favour its transition into fresh and probably brittle martensite leading to decrease of fracture toughness within such areas.

Authors of paper [4] indicated that such adverse for fracture toughness result of presence of mechanically unstable retained austenite in the structure is particularly dangerous in tool steels. Progressive transformation of mechanically unstable austenite into fresh martensite may result in stress increase in their volume and lead to initiation of cracks inside them.

An advantageous influence of retained austenite on fracture toughness for the first time was pointed in works [5-9]. It was stated that increase of retained austenite content properly distributed in the structure of a steel would only not reduce the fracture toughness of these steels but strongly increase it.

Quoted results of the research so far conducted indicate that major cause of discrepancies between opinions on retained austenite on fracture toughness of steel is its stability. Therefore, despite 35 years of research in various scientific institutions all over the world, there is no common and unequivocal opinion as yet on role played by retained austenite in the process of steel cracking. Such issue seems to be surprising, since fracture toughness is one of the most important characteristic of tool steel and retained austenite itself is a phase present in the structure of many steels subjected to hardening treatment.

2. Material and its heat treatment

The chemical composition of tested steel is shown in Table 1.

Table 1
Chemical composition of 70MnCrMoV9-2-4-2 steel

mass %								
C	Mn	Si	Cr	P	S	Mo	Ni	V
0.70	2.15	0.30	0.54	0.015	0.005	0.44	0.13	0.16

All samples for testing were austenitized at 820°C (for 30 min.) and quenched in oil. In order to diversify the content of retained austenite some of the samples were subjected to cold treatment in liquid nitrogen for 60 min after hardening. All samples were tempered for 2 hours. The temperatures at which the samples were to be tempered had been determined on the basis of knowledge of phase transformation kinetics during heating from hardened state which is described by CHT (Continuous Heating Transformations) diagrams [10-12]. From diagram of phase transformation kinetics during tempering for 70MnCrMoV9-2-4-2 steel [13] the following temperatures were selected: 120, 170, 220, 300, 350 and 400°C. Each version of heat treatment was represented by 3 samples.

3. Investigation methods

Hardness testing was conducted using Vickers apparatus with 30 kG load.

The investigations of fracture toughness were performed according to PN-EN ISO 12737, on the samples of 10x20x100 mm with a cut notch 8 mm deep and 1.2 mm wide, with a method of linear-elastic fracture mechanics using INSTRON testing machine. Samples were fractured with three-point bending method.

Impact strength testing was conducted using 150J impact testing machine on samples KCU2 type.

The evaluation of volume fraction of retained austenite was performed on polished transverse microsections from the samples to K_{Ic} test. The method of X-ray diffraction was used, filtered radiation of the cobalt tube - $Co_{K\alpha}$.

Fractographic investigation was made using scanning microscope with magnification of 500 and 2000x.

4. Research results and discussion

The results of influence of tempering temperature on hardness of tested steel samples, assigned for fracture toughness testing (K_{Ic}) are shown in Fig. 1. Whereas Fig. 2 presents the influence of tempering temperature on retained austenite content in the same samples.

One may notice that along with the increase of tempering temperature the hardness of tested steel is decreasing. Cold treated samples keep higher hardness within whole range of temperatures what indicates that after quenching part of retained austenite has transformed into martensite.

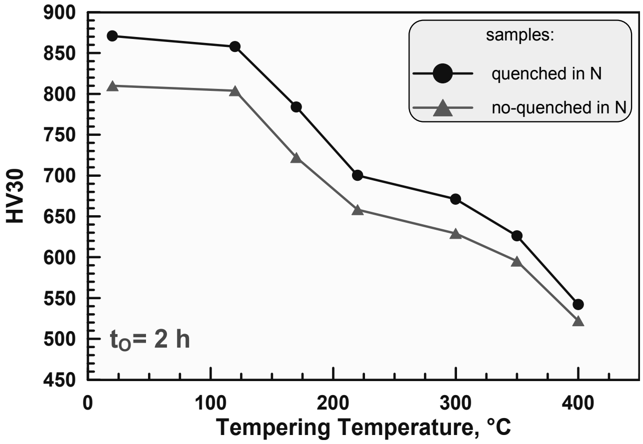

Fig. 1. Influence of tempering temperature on hardness HV30 of tested steel after hardening from 820°C

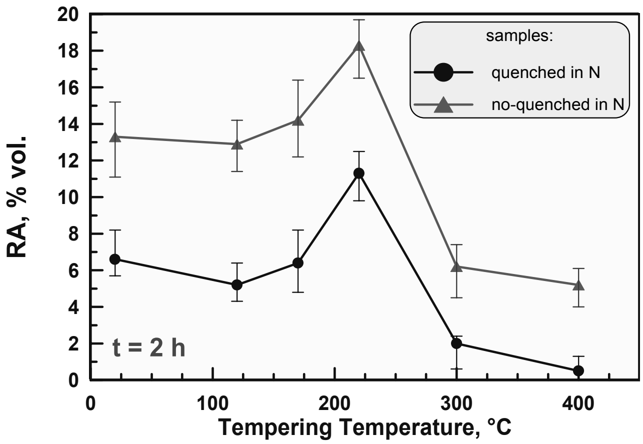

Fig. 2. Influence of tempering temperature on volume fraction of retained austenite in 70MnCrMoV9-2-4-2 steel after hardening from 820°C

After tempering at temperature 170 and 220°C for both cold and no-quenched intensification of hardness decrease was observed (compare to Fig. 1). It would follow from CHT diagram for tested steel [13]. The effect of most intensive softening may be corresponding to ε carbide precipitation. However, it is important to point out that according to Fig. 2 this intensification of softening between 170 and 220°C is accompanied by increase in volume fraction of retained austenite what also would contribute to decreasing hardness of tested steel.

With tempering temperature increasing from 220°C to 300°C, a slowing down of tendency for softening of 70MnCrMoV9-2-4-2 steel is observed. Simultaneously within the same temperature range (Fig. 2) sudden drop of the retained austenite fraction is observed due to of thermal destabilization of this phase [13]. Therefore, one may presume that final hardness of samples tempered at 300°C was influenced by two effects: precipitation of carbon excess from tempered martensite and thermal destabilization of soft retained austenite and its transition into fresh, hard martensite (or bainite).

Similar hardness values for both quenched and no-quenched in N steel tempered at 400°C (Fig. 1) result from intensive thermal destabilization of retained austenite. This phase no longer influences on hardness of tested steel.

In Fig. 2 retained austenite fraction increase in a samples tempered at 170 and 220°C irrespective of whether they were cold treated or not. Such changes in fraction of retained austenite with tempering temperature shall not be considered as unexpected since similar changes have already been recorded during the test and even for different grades of steel [14, 15].

Changes of retained austenite fraction in the samples from tested steel correlated with fracture toughness for stress intensity factor K_{Ic} are shown in Fig. 3 while for impact strength in Fig. 4.

As one may notice, the character of K_{Ic} factor and KCU2 impact strength changes with tempering temperature is nearly alike. In both diagrams, within the whole tempering temperatures range, the fracture toughness of tested steel reaches local maximum after tempering at 220°C while tempering at 300°C resulted in decrease of its fracture toughness to local minimum.

Since impact strength (work of breaking) is a sum of nucleation work and work of crack propagation, while K_{Ic} factor is a measure of steel resistance to cracks propagation only, one may state that it is a way of cracks propagation in the steel that determines the fracture toughness of 70MnCrMoV9-2-4-2 steel.

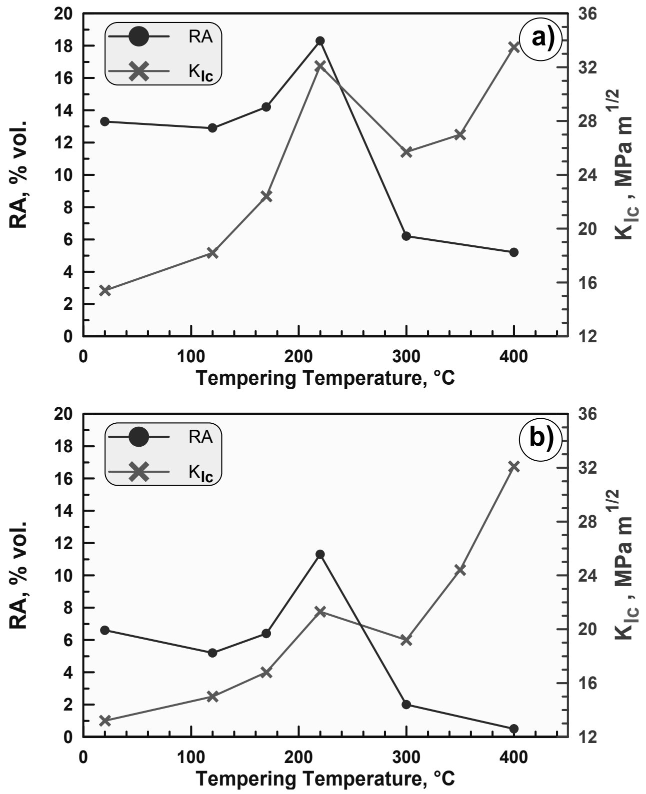

Fig. 3 Influence of tempering temperature on stress intensity factor (K_{Ic}) and on fraction of retained austenite (% vol.) in quenched from 820°C steel 70MnCrMoV9-2-4-2 in state: a) without cold treatment; b) after cold treatment at -196°C

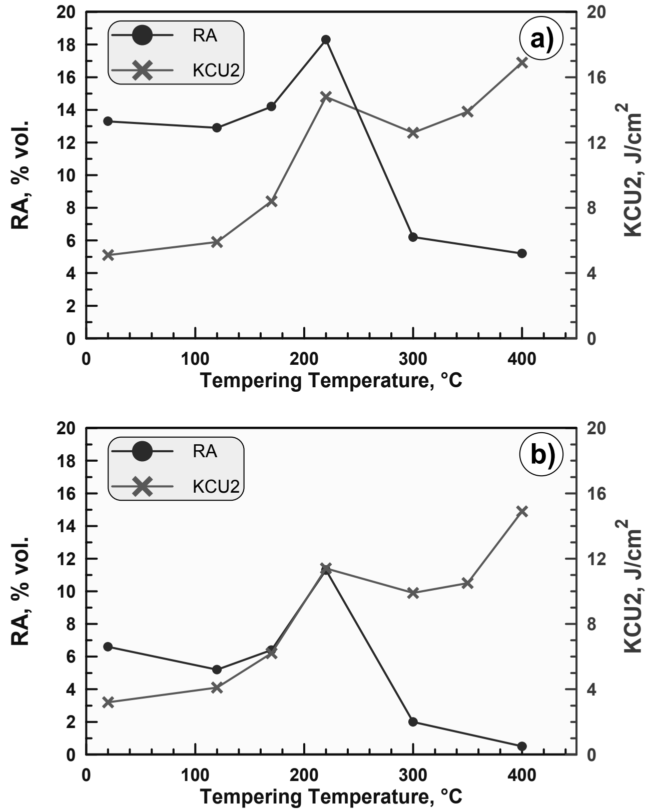

Fig. 4. Influence of tempering temperature on impact strength (KCU2) and fraction of retained austenite (% vol.) in quenched from 820°C steel 70MnCrMoV9-2-4-2 in state: a) without cold treatment; b) after cold treatment at -196°C

The cold treated samples (both for K_{Ic} and impact strength tests), with less amount of retained austenite, exhibited lower fracture toughness within the whole tempering temperatures interval. This observation proves that retained austenite increases fracture toughness of the steel.

It is easy to notice that increase of tempering temperature from 120 to 220°C resulted in distinct, high increase of K_{Ic} factor as well as of KCU2 impact strength. Increase of fracture toughness observed within this range of temperatures has relationship with development of tempering processes and softening of the structure. However, one can to notice in both figures increment of fracture toughness up to local maximum at 220°C. This is accompanied by increase of retained austenite fraction in the structure of test samples and even irrespective of whether they have been cold treated or not before tempering.

However, it is worth to notice (Fig. 3 and Fig. 4) that during tempering at 300°C, fracture toughness of the samples reached local minimum, and there was found a significant decrease of retained austenite fraction in the structure of the samples. Besides, cold treatment in liquid nitrogen turned out to be meaningless because decrease of fraction of retained austenite occurred in both cases of samples i.e. with cold treatment as well as without it and in both types of samples it was accompanied by decrease of fracture toughness. Therefore one may suppose that, in spite of proven advantageous influence of retained austenite presence to fracture toughness, its thermal destabilization at 300°C may be one of the reason why temper brittleness of the first type occurs.

One should not forget, in accordance with the opinions expressed in [16, 17], that main cause for temper brittleness may be dissolution of ε carbide and redistribution of carbon not only to sites of stabile phase nucleation (cementite) but also to dislocation tangles determining e.g. boundaries of cellular structure. Thus it is possible with high probability to assume that after tempering of tested steel above 220°C a true decrease of fracture toughness, following from $\varepsilon \rightarrow M_3C$ transition, would be even greater, if present in structure retained austenite didn't hinder this tendency.

5. Conclusions

1. Retained austenite in the structure of 70MnCrMoV9-2-4-2 steel after hardening increased its fracture toughness proportionally to its content. Such advantageous influence of this phase was also found after tempering tested steel at temperatures within the range of 120-400°C.
2. Phenomenon of temper brittleness of first type found in 70MnCrMoV9-2-4-2 steel may be at least partially related to thermal destabilization of retained austenite and its transition into martensite or bainite. Research results presented in this paper let hope that know-how of such heat treatment, which would make possible to stabilize this phase in the structure of hardened steels, would contribute not only to restrain temper brittleness but even to complete elimination of this adverse phenomenon, if the structure contained adequate amount of stable retained austenite.
3. After tempering tested steel at 120°C no distinct changes in fraction of retained austenite in comparison with hardened state were observed. Simultaneously, it was found that such low tempering results in very strong stabilization of the phase. For this reason, from selection of optimal technology of heat treatment, the temperature may be recognized as optimal for tempering of 70MnCrMoV9-2-4-2 steel.
4. After tempering tested steel above 220°C retained austenite was subject to thermal destabilization and was transforming into fresh martensite or bainite. However it was found that such transition of austenite was accompanied by decrease of fracture toughness, therefore it is recommended to temper tools made of tested steel at temperature not higher than 220°C.

References

[1] V.T.T Miihkinen, D.V. Edmonds, Fracture toughness of two experimental high-strength bainitic low-alloy steel containing silicon, Material Science and Technology 3 (1987) 441-449.

[2] R.O. Ritchie, R.M Horn, Further considerations on the inconsistency in toughness evaluations of AISI 4340 steel austenitized at increasing temperatures, Metallurgical Transactions 9A/3 (1978) 331-341.

[3] G. Thomas, Retained austenite and tempered martensite embrittlement, Metallurgical Transactions 9A (1978) 439-450.

[4] A. Mazur, J. Pacyna, T. Paluszkiewicz, J. Krawiarz, T. Skrzypek, The Influence of heat treatment parameters on susceptibility to cracking of hardener rolls. Report of AGH Metallurgy Institute 8/G (1978) (in Polish).

[5] V.F. Zackay, E.R. Parker, W.E. Wood, Influence of some microstructural features on the fracture toughness of high strength steels, Proceedings of the 3rd International Conference "Strength of metals and alloys", Cambridge 1973, 175-188.

[6] V.F. Zackay, E.R. Parker, J.W. Morris Jr, G. Thomas, The application of materials science to the design of engineering alloys. A Review, Materials Science and Engineering 16 (1974) 201-221.

[7] G.Y. Lai, W.E. Wood, R.A. Clark, V.F. Zackay, E.R. Parker, The effect of austenitizing temperature on the microstructure and mechanical properties of As-quenched 4340 steel, Metallurgical Transactions 5/7 (1974) 1663-1670.

[8] J. Pacyna, The effect of retained austenite on the fracture toughness of high speed steels, Steel Research 58 (1987) 87-92.

[9] J. Pacyna, Retained austenite in the cracking process of steel on the working rolls of the cold sheet rolling mill, Steel Research 63 (1992) 500-503.

[10] P. Bała, J. Pacyna, J. Krawczyk, The kinetics of phase transformations during the tempering HS6-5-2 high-speed steel, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 47-50.

[11] P. Bała, J. Pacyna, J. Krawczyk, The kinetics of phase transformations during the tempering HS18-0-1 high-speed steel, Journal of Achievements in Materials and Manufacturing Engineering 19/1 (2006) 19-25.

[12] P. Bała, J. Pacyna, The kinetics of phase transformations during tempering in high-speed steels, Journal of Achievements in Materials and Manufacturing Engineering 23/2 (2007) 15-18.

[13] A. Kokosza, The effect of retained austenite on the fracture toughness of steel, Ph.D thesis, AGH-UST, Krakow, 2004 (in Polish).

[14] K.P. Balan, A. Venugopal Reddy, D.S. Sarma, Austenite precipitation during tempering in 16Cr-2Ni martensitic stainless steels, Scripta Materialia 39/7 (1998) 901-905.

[15] J. Pacyna, J. Krawczyk, R. Wygonik, The problem of retained austenite at tempering of steels, Proceedings of the 9th International Scientific Conference „Achievements in Mechanical and Materials Engineering" AMME'2000, Gliwice–Sopot–Gdańsk, 2000, 415-420 (in Polish).

[16] J. Pacyna, B. Pawłowski, The effect of the tempering temperature on 30HGSNA steel toughness, Metallurgy and Foundry Engineering 10 (1984) 409-421.

[17] J. Pacyna, A. Kokosza: Irreversible Temper Brittleness in the manganese content alloys, Proceedings of the 10th Jubilee International Scientific Conference „Achievements in Mechanical and Materials Engineering" AMME'2001, Gliwice–Zakopane, 2001, 423-428 (in Polish).