

THREE MAIN SOLIDIFICATION REACTIONS OF VANADIUM MODIFIED T1 –TUNGSTEN HIGH SPEED TOOL STEEL

Hossam Halfa

Steel Technology Department, Central Metallurgical R&D Institute (CMRDI), Helwan, Egypt, <u>hossamhalfa@cmrdi.sci.eg</u>; <u>http://www.cmrdi.sci.eg</u>

Abstract

AISI T1 high speed steel was modified with the replacement of 5% W by 1% V with and without extra carbon addition. The solidification reactions, temperature of precipitation starting of precipitated carbides were evaluated and compared with those of the standard AISI T1 steels.

In this work, thermo-dynamical equilibria have been calculated for high speed tool steel (HSS), AISI T1 composition belonging to the multicomponent system Fe–C–Cr–W–Mo as well as for its three different variant containing vanadium.

The experimental results show that the substitution of tungsten with vanadium and/or carbon in HSS 18-0-1 steel has influence mainly the three main solidification reactions during solidification of investigated steels from the melts. In addition, the substitution of tungsten with vanadium and/or carbon in HSS 18-0-1 steel has influence mainly the stability of gamma austenite and temperature of precipitation beginning of MC and M_6C type carbides which have great influence on the chemical composition of precipitation.

Keywords: Thermo-calc; High-Speed tool steel; Carbides; Precipitates

1. INTRODUCTION

High speed steels owe its name to ability of fast machining and cutting of various materials among others the alloys with iron matrix. They are characterized by high content of carbon and other alloying elements, mainly carbide forming, such as W, Mo, V and Cr. Some types of high speed steels contain also Co [1-3].

One of more important attributes of these steels are their cutting properties dependent on wear resistance, impact resistance and the resistance to heat tempering. Wear resistance depends on the type, content and form of primary carbides (MC, M_6C) and matrix hardness [4,5]. Whereas the impact resistance is determined by the state of tempered matrix, grain size of former austenite, spatial arrangement and size distribution of primary carbides. Matrix of high speed steels consists of well-tempered martensite and the carbides causing secondary hardness [1, 3].

Among numerous research conducted in recent years on high speed steels one may distinguish the research on modification of chemical composition [6], phase transformations during tempering [7] and the surface properties of tools made of high speed steels [8,9].

In this work, thermo-dynamical equilibria have been calculated for high speed tool steel (HSS), AISI T1 composition belonging to the multicomponent system Fe–C–Cr–W–Mo as well as for its three different variant containing vanadium.

Main objective of the research presented in this work was the evaluation of the influence of replacement of tungsten by vanadium or vanadium and carbon on phase transformation during solidification of T1-high speed tool steel.



2. EXPERIMENTAL WORK:

2.1. Chemical Compositions Designing

At this work in investigated high speed tool steels the tungsten content was partly substituted by alloying elements that form harder carbides, like vanadium. In this approach, tungsten will partly substitute by vanadium: one percent of vanadium equivalent five percent of tungsten. On the other hand, Based on the method of definite proportion of carbon, the effect of secondary hardening is optimal when alloy elements and carbon contents meet the constant proportion of molecular formula of carbide [10]. The mass ratio of vanadium to carbon is 1:0.235 in VC. Given higher vanadium content than the chemical proportion of VC, the remaining V only dissolves in the matrix after forming VC, which will lead to decreasing hardness of material because of lack of carbon in matrix. Given higher carbon content than the chemical proportion of VC, however the remaining carbon not only dissolves in matrix but also forms other carbides, which will promote increasing hardness and wear resistance of material. Therefore, the ratio of vanadium to carbon is designed higher than the chemical proportion of VC. On the other hand, to enhance the hardness of material, about 4% chromium was mixed in tested alloy.

2.2. Thermo-Calc Experimental

The thermodynamic calculations were done using Thermo-Calc [11] version R running on PC/Windows NT and the optimized SGTE database, together with data for other edge binaries and higher-order systems (M1–M2, M1–M2–C, M1–M2–Fe,). Thermo-dynamical Equilibria have been calculated for investigated high speed tool steel, AISI T1 composition belonging to the multi-component system Fe–C–Cr–W–V as well as for its three different variant containing vanadium. All phases in the database are described according to a sublattice model [12,13].

3. RESULTS & DISCUSSION

Two different groups (C-W-Cr-V) of high speed tool steel, with constant chromium content and differing tungsten, vanadium and/or carbon contents in comparison with standard stee1 AISI T1 were studied. The nominal compositions of these steels, in weight percent, are provided in **Table** 1.

The many essential alloy additions to iron (C, W, V, Cr) make the high speed tool steel, HSS a complex multi-component system. Its complete experimental investigation would require enormous time and effort. Instead, the CALPHAD method has been successfully used for computation of phase equilibrium the multi-component HSS system. In the present work, the Thermo- Calc program has been applied to the system Fe-C-W-Cr-V with the thermodynamic information contained in the solid-solution-database of the SGTE (Scientific Group Thermo-data Europe) [14]. **Fig.** 1 shows the temperature-concentration diagram for both class of the steel between 900°C and 1500°C, calculated by **Thermo-Calc**.

6	Steel no	Chemical Composition, wt. %				
Group		С	Cr	w	v	Fe
Standard steel	1V-18W	0.75	4	18	1	Balance
A (Vanadium modified)	2V-13W	0.75	4	13	2	Balance
	3V-8W	0.75	4	8	3	Balance
	4V-3W	0.75	4	5	4	Balance
в	2V-13W HC	0.985	4	13	2	Balance
(Carbonand vanadium modified)	3V-8W HC	1.22	4	8	3	Balance
	4V-3W HC	1.455	4	5	4	Balance

Table 1. The	e chemical	composition	of tested	steels
--------------	------------	-------------	-----------	--------





Fig.1. A) through D) temperature- concentration (TC) sections for standard HSS, AISI T1 and its vanadium variants.

3.1. Solidification of Investigated Steels

Table 2 shows the starting temperature for different phases during solidification from the melt present on the investigated steels. **Table 2** indicates a decrease in solidus temperature and changes in liquidus temperature in agreement with the chemical composition variation in the investigated steels. In addition, MC carbides solvus temperature increase and M_6C carbides solvus temperature decrease with variation of chemical composition of investigated steels in order 1V-18W, 2V-13W, 3V-8W and 4V-3W steels. From **Table 2**, we can say that modification occurs has a great effect on the three main solidification reactions and starting temperature of different phases.

	Standard	Va	nadium mod	ified	Vanadium and Carbon modified		
Phases	T1-1V-18W	T1-4V-3W	T1-3V-8W	T1-2V-13W	T1-4V-3W	T1-3V-8W	T1-2V- 13W
Liquids	<u>></u> 1459	<u>></u> 1467	<u>></u> 1464	<u>></u> 1462	<u>></u> 1402	<u>></u> 1407	<u>≥</u> 1423
Solidus	1320	1293	1277	1301	1268	1250	1251
BCC	<u><</u> 1459	<u><</u> 1467	<u><</u> 1464	<u><</u> 1462	800	810	1423
FCC	1354	1393	1369	1337	1402	1407	1375
МС	895	1294	1278	1155	1283	1268	1254
M ₆ C	1324	838	1285	1310	xxx	xxx	1307
M ₇ C ₃	829	xxx	Ххх	761	900	885	883
M ₂₃ C ₆	663	ххх	429	Ххх	xxx	xxx	ххх

Table 2. The starting temperature for different phases during solidification from the melt present on the investigated steels.

3.1.1. Solidification of 1V-18W Steel

Fig. 2.A shows the phase fraction diagram for the 1V-18W steel with fixed carbon content. At the beginning of the cooling stage the delta-ferrite solidifies first from the melt in the form of primary dendrites, according to the reaction (1), beginning at around $1460 \circ C$.

$$L \rightarrow delta$$
-ferrite (1)

As the separation of delta ferrite proceeds, the carbon content increases in the melt; solidification continues as a peritectic reaction. Transformation delta ferrite to austenite at around 1354 °C, according to:

L + delta ferrite
$$\rightarrow$$
 gamma austenite (2)





Fig. 2. Temperature dependence of the amounts of phases for standard HSS, AISI T1 and its vanadium variants..

When the liquid is leaving peritectic point, ferrite should normally be completely transformed to austenite. Then the un-solidified melt follows the eutectic reaction, producing austenite plus carbides, as shown in equ. (3).

 $L \rightarrow \text{gamma austenite} + M_6 C$ (3)

As we mentioned previously, two kinds of carbide are present in the eutectic. Globular carbides, identified as M_6 Ccarbides, are grown in the interdendritic eutectic in contact with the austenite dendrites, as it may be anticipated from reaction (3). The MC carbides nucleate on them and precipitate in final stage of solid-phase transformation at temperature around 900 °C. In this work, we can state that the M_6 C carbide solidified from the residual liquid at around 1324 °C and solidified before MC carbide.

3.1.2. Vanadium Modified Variant

A. Solidification of 2V-13W Steel

Fig. 2.B shows the phase fraction diagram for the 2V-13W steel. With the assistance of Fig. 1 and **2**, we can see that the three main solidification reaction of this steel is the same as 1V-18W steel (standard steel) but at different temperature as shown in **Table 2**.

B. Solidification of 3V-8W Steel

Fig. 1.C and **2.C** show that the solidification steps of 3V-8W steel. Due to decrease of temperature during cooling delta ferrite solidified first from the melt, according to the reaction (1), beginning at around 1464 °C. The volume fraction of gamma austenite phase increases by decreasing the melt temperature and, simultaneously the remaining liquid is saturated by carbon and alloy elements. Residual melts and gamma austenite form gamma austenite plus carbides (MC and M₆C carbides almost at the same temperature) during the reaction of eutectic as shown in equ. (3) and **Table 2**. So third solidification reaction can be changed into the following

$L \rightarrow \text{gamma austenite + carbides (M_6C + MC)}$ (3)

Table 2. confirmed that, MC precipitate first then M_6C at temperature 1278 and 1285 °C respectively. According to the equation 3 and **Table 2**, we can conclude that M_6C and MC carbides almost precipitated simultaneously and that the cause of fine expected structure of MC carbides as a result of short contact time of these carbides individually with the melt to grow and consequently M_6C start to precipitate.

C. Solidification of 4V-3W Steel

Fig. 1.D and **2.D** show the phase fraction diagram for the 4V-3W steel with constant carbon content. The first two solidification reaction of steel 4V-3W is the same as all vanadium modified steels under investigation on





the other hand third solidification reaction is difference. The third main solidification reaction of this steel can be written as follow

$L \rightarrow$ gamma austenite + carbide (MC) (3)

In this work, we can state that the MC carbide solidified from the residual liquid at around 1277 \circ C and solidified before M₆C carbide, as shown in **Table 2**. However, the MC carbides predominate in the eutectic and their formation in expense of the M₆C carbides is justified, because MC is favored from a relatively high carbon and vanadium content in the melt.

3.1.3. Vanadium and Carbon Modified Variants

A. Solidification of 2V-13W Steel

By study solidification diagram **Fig. 3.A** and isopleths phase diagram **Fig. 1.b** but at higher carbon content, this **Figs.** show that the first three main solidification reactions for 2V-13W vanadium and carbon modified steel is the same with the vanadium modified steel but the difference is the temperature of the starting temperature of phase precipitation for solidified steel from the melt as shown in **Table 2**.

B. Solidification of 3V-8W Steel

Solidification of 3V-8W carbon and vanadium modified steel start from the region of liquid plus gamma austenite, as shown in **Fig. 1.C** and **3.D**. The main solid–liquid reactions proceed during solidification of the melts as follow:

i) Austenite precipitates from the melts (from 1407 °C) :





The volume fraction of austenite phase increases by decreasing the melt temperature and, simultaneously the remaining liquid is saturated by carbon and alloy elements. Residual melts and austenite form MC carbides during the reaction of eutectic as shown in **Fig. 1.C and 3.B**.

(ii) Eutectic transformation (from 1268 °C):

L ----- gamma austenite + MC (5)

A eutectic reaction occurs between carbon and alloying agents such as V, W, Cr in the retained melts. The result of the reaction is composed of eutectic carbides and austenite. This reaction completes the solidification process.

(iii) Finally, the M_7C_3 phase is formed as part of the solid transformation (from 883 °C):

gamma austenite ----- $BCC + M_7C_3$ (6)



C. Solidification of 4V-3W Steel

Fig. 3.C shows that solidification of 4V-3W vanadium and carbon modified steel start from the region of liquid plus gamma austenite. The first two main solid–liquid reactions proceed during solidification of the melts as reactions equ. (4) and equ. (5) but at different temperature as shown in **Table 2**. Finally, the M_7C_3 and MC_SHIP phases are formed as part of the solid transformation (from 900 °C and from 798 °C respectively):

gamma austenite	$BCC + M_7C_3$	(6)
gamma austenite	BCC + + MC_SHIP	(7)

According to equ. (7), MC_ SHIP carbides precipitated during cooling at low temperature due to higher content of vanadium and carbon in the matrix of this steel. From previous results we can conclude that, tungsten partly substitute by vanadium and/or carbon to investigated steels promotes the formation of MC type carbides instead of M_6C type carbides. Also the higher vanadium and carbon content promote formation of secondary carbides for example M_7C_3 and MC_SHIP carbides which result from solid transformation during solidification.

CONCLUSIONS

The following conclusion can be drawn:

1. The substitution of tungsten with vanadium and/or carbon in HSS 18-0-1 steel has influence mainly the three main solidification reactions during solidification of investigated steels from the melts.

2. The substitution of tungsten with vanadium and/or carbon in HSS 18-0-1 steel has influence mainly the stability of gamma austenite and temperature of precipitation beginning of MC and M_6C type carbides.

3. Standard steel 1V-18W contained higher total carbides than all investigated steels and the main carbides is M_6C .

4. The substitution of tungsten with vanadium and/or carbon in HSS 18-0-1 steel promotes MC carbides precipitation instead of MC.

REFERENCES

- [1] A. K. Sinha, Physical metallurgy handbook, The McGraw- Hill Companies, Inc., New York, 2003.
- [2] R.W.K. Honeycombe, H.K.D.H. Bhadeshia, Steels. microstructure and properties, Second Edition. Edward Arnold, London, 1995.
- [3] M. Blicharski, Steels, WNT, Warsaw, 2004 (in Polish).
- [4] S. Karagoes and H. O. Andren: Z. Metallkd., (1992), 386.
- [5] S. Karagoz, H.F. Fischmeister: Metall. Trans. A: 1998, vol. 29A, 205.
- [6] L.A. Dobrzański, A. Zarychta: Journal of Materials Processing Technology 77 (1998) 180-193.
- [7] M. Wang, Y. Wang, F. Sun: Materials Science and Engineering A 438-440 (2006) 1139-1142.
- [8] T.H. Yu, C.Y. Chen, J.R. Yang: Journal of Materials Engineering and Performance 16 (2007) 102-108.
- [9] X.T. Wang, Metal Materials, Mechanical Industry Press, Beijing, 1988, p.131.
- [10] B. Sundman, B. Jansson, B J.-O. Andersson: Calphad, 9 (1985), No. 2, 153
- [11] B. Sundman and J. Ågren, J. Phys. Chem. Solids 42(1981), pp. 297.
- [12] H. Halfa," Characterization of Electroslag Remelted Super Hard High Speed Tool Steel Containing Niobium", Steel Research Int. 84 (2013) (online)
- [13] G.C. Coelho, J.A. Golczewski, and H.F. Fischmeister : Metall. Trans. 2003, vol. 34A, 1749.
- [14] SGTE Solution Database, Version **2006**, provided by Thermo-Calc Software AB, Stockholm, Sweden (www.thermocalc.se).