MECHANICAL AND CREEP PROPERTIES OF P92 STEEL WITH DIFFERENT DELTA FERRITE CONTENT

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Abstract

This work deals with properties and microstructure of heat resistant chromium steel P92. This steel is considered to be one of the best modified 9-12 % Cr steel for the construction of coal power plants with ultra-super-critical steam parameters. High creep rupture strength of steel P92 is determined by its chemical composition and by microstructure as well. Optimal microstructure of steel P92 is ideally composed of homogeneous martensite and fine dispersion of secondary particles.

During the experiments one P92 heat with an occurrence of more than 20 % delta ferrite was produced. The results of this heat are confronted with mechanical and creep properties of another heat without delta ferrite in the microstructure. Conclusions relate to the influence of delta ferrite on mechanical and creep properties of P92 steel.

Keywords: Delta ferrite, mechanical properties, creep, steel P92

1. INTRODUCTION

High creep resistance of modified chromium steels is done by precipitation of vanadium nitrides. These very finely dispersed and stable particles effectively prevent the movement of dislocations and thereby slow down the creep. Vanadium nitrides precipitate not only during tempering but also during creep exposure, especially on dislocations within subgrains [1]. Higher creep resistance can be thus expected in steels with high density of dislocations. It follows that the desired microstructure for the steel structure is martensitic [2].

In addition to dispersion hardening, which is caused by vanadium nitrides and $M_{23}C_6$ particles, a solid solution strengthening is involved in high creep resistance of steel P92. This is due to substitution elements Mo and W dissolved in the solid solution. The maximum value of creep rupture strength according to the Japanese authors is reached with 1.8 % W and 0.5 % Mo [3].

The product of martensitic transformation in steel P92 is lath martensite, which is formed in a wide range of cooling rate. Inside the original austenitic grains creates several parallel martensitic laths that may be separated by films of residual austenite. Establishment of ferritic-carbidic components in the microstructure at very slow cooling rate is accompanied by a sharp drop in hardness of the material. The decrease in hardness of martensite at the medium cooling rates is associated with the occurrence of ε-carbide or cementite in martensite [4].

Cementite in the steel is not stable minor phase and during tempering it is rapidly dissolved [5]. Depending on the chemical composition of steel a small amount of δ-ferrite can be also presented in the microstructure [4].

Delta ferrite can be stable even after forging or after austenitization. The delta ferrite in steel P92 has very adverse effects, its presence reduces the hardenability and toughness of steel, significantly degrades creep properties. Stability of delta ferrite depends on the balance between austenite-forming elements Ni, Mn, Cu, C, N and ferrite-forming elements Cr, Si, Mo, W, V and Nb. Influence of chemical composition can be expressed e.g. by specific chromium equivalent Cr_{ekv} [6].

$$Cr_{ekv} = Cr + 6Si + 4Mo + 1{,}5W + 11V + 5Nb + 8Ti + 12Al - 40C - 30N - 4Ni - 2Mn - 2Co - Cu \qquad (1)$$

The work [6] shows that when the value of the Cr equivalent is less than 10, no delta-ferrite can be expected in microstructure. If the value of the Cr-equivalent is in the range between 10 and 12 smaller quantities of δ-ferrite may occur. Higher values of Cr-equivalent mean high content of δ -ferrite in the structure of steel P92 [6].

This work aims to confirm the harmful effect of delta ferrite on the mechanical and creep properties of P92 steel.

2. EXPERIMENTAL MATERIAL

Two heats of steel P92 were analysed during this project. Chemical composition of investigated heats is shown in **Table 1**.

Table 1 Comparison of the chemical composition of cast steel P92

Heat	C	Mn	Si	Cr	Mo	V	W	Ni	Nb	Al	N	Cr_{ekv}
	(wt%)											(-)
A	0.090	0.51	0.33	8.50	0.52	0.21	1.70	0.20	0.060	0.020	0.0345	10.322
B	0.090	0.50	0.34	8.85	0.50	0.21	1.90	0.31	0.084	0.008	0.0595	9.752

The heat A revealed a large amount of delta ferrite, approx. 21 %. The calculated value of Cr equivalent of the heat is 10.322. Such value admits the presence of small quantities of delta ferrite in the structure, but not 21 %. The reason of such high amount of delta ferrite cannot only be the chemical composition of the heat. Substantial inhomogeneity of chemical composition probably caused sharp increase in local content of ferrite-forming elements, which resulted in the emergence of delta ferrite islets. **Figure 1** shows the microstructure of the sample A annealed at 1050 °C for 2 hours and then cooled in oil. White islets are particles of delta ferrite.

Heat B shows no delta ferrite in microstructure ($Cr_{ekv} = 9.752$). After complete heat treatment the microstructure is homogenous, consisting of tempered martensite, see **Figure 2.**

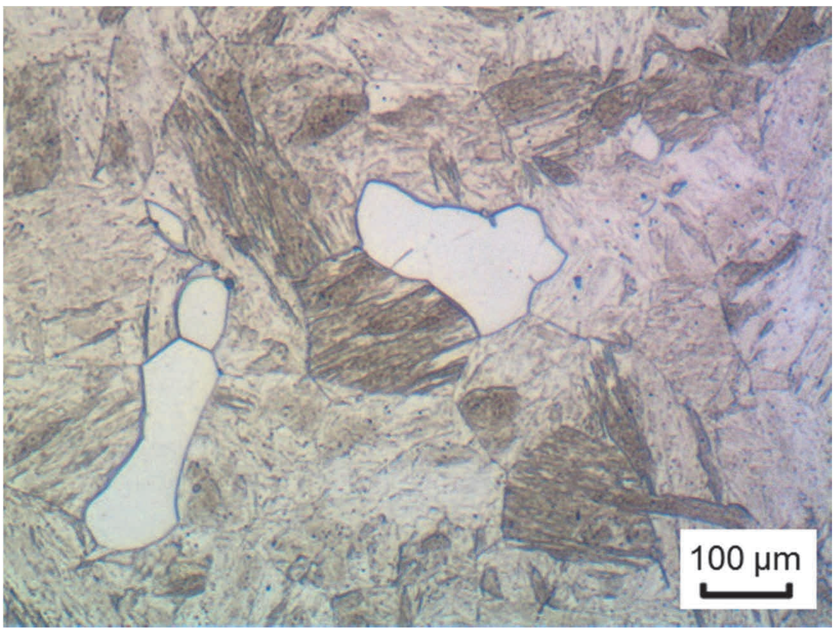

Figure 1 Microstructure of sample of heat A, austenitization at 1050 °C / 120 min., cooling in oil.

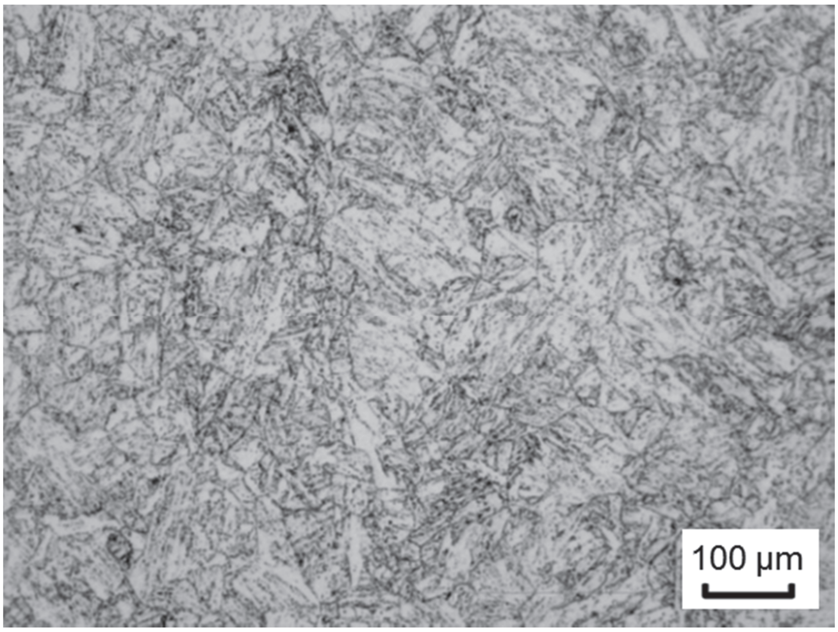

Figure 2 Microstructure of sample of heat B, austenitization at 1060 °C / 180 min., cooling in water + tempering at 770 °C / 240 min.

3. RESULTS AND DISCUSSION

Samples from all heats were subjected to several regimes of heat treatment, i.e. normalizing and tempering. As a cooling medium was used water or oil. Subsequently, mechanical testing was carried out together with creep tests of heat A and heat B. The results of mechanical properties are presented in **Table 2** and **Table 3.**

Heat A reached higher strength and toughness properties after quenching in water (A-W). Heat B after water quenching showed relatively high strength characteristics, but the elongation value was low, even lower than the required minimum value of 19 % according to EN 10216-2 [7].

Table 2 Mechanical properties of heat A, Samples after heat treatment 1060 °C / 330 min. + 770 °C / 330 min., A-W cooling in water, A-O cooling in oil

	$R_{p0,2}$ at 20 °C	**R_m at 20 °C**	**A_5 at 20 °C longitudinal**	**KV at 20 °C longitudinal**	**KV at 20 °C transverse**	**$R_{p0,2}$ at 600 °C**
	(MPa)	(MPa)	(%)	(J)	(J)	(MPa)
A-O	481	649	21	117	89	298
A-W	499	668	23.4	153	92	295

Table 3 Mechanical properties of heat B, Samples after heat treatment 1060 °C / 180 min. + 770 °C / 240 min., B-W cooling in water

	$R_{p0,2}$ at 20 °C	**R_m at 20 °C**	**A_5 at 20 °C longitudinal**	**KV at 20 °C longitudinal**	**KV at 20 °C transverse**	**$R_{p0,2}$ at 600 °C**
	(MPa)	(MPa)	(%)	(J)	(J)	(MPa)
B-W	554	726	18.4	137	63	358

Figure 3 and **Figure 4** shows the current results of creep tests for heats A and B. Larson-Miller parametric equation was used for construction of these diagrams:

$$P_{LM} = T(25 + log(t)) \quad (2)$$

Where T is the absolute temperature [K], t is the time to rupture [h] and $L - M$ constant C = 25 represents value usually used in chromium modified steels [8, 9].

The curves in diagrams 3 and 4 show a dramatic difference in creep properties of heat A and B. Results of heat B lie between standardized mean curve and the allowed -20 % range (dashed line). Values of heat A however lie below the allowed -20 % range. Such a result means that this heat has no potential to meet the requirement of creep resistance of grade P92.

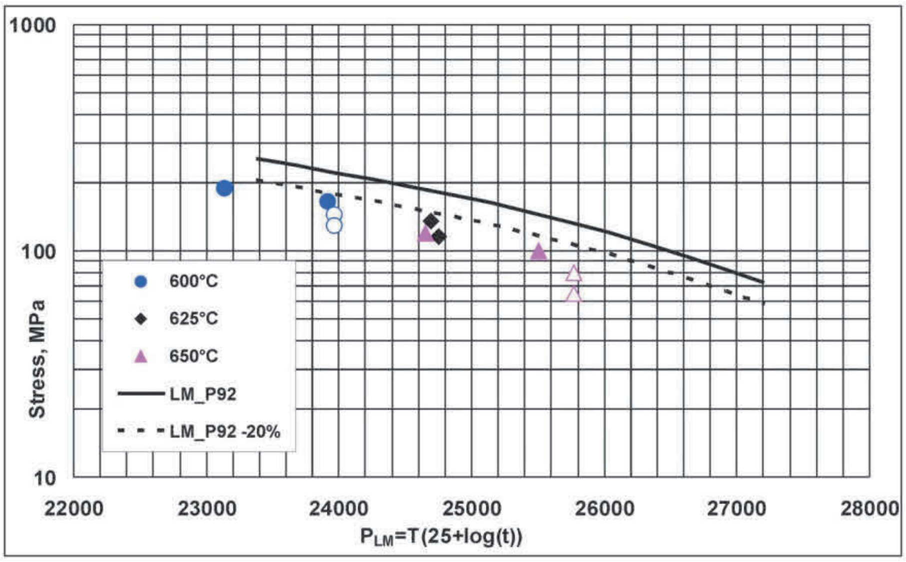

Figure 3 Dependence of stress on the Larson-Miller parameter for the heat A in comparison to the standardized mean values for steel P92

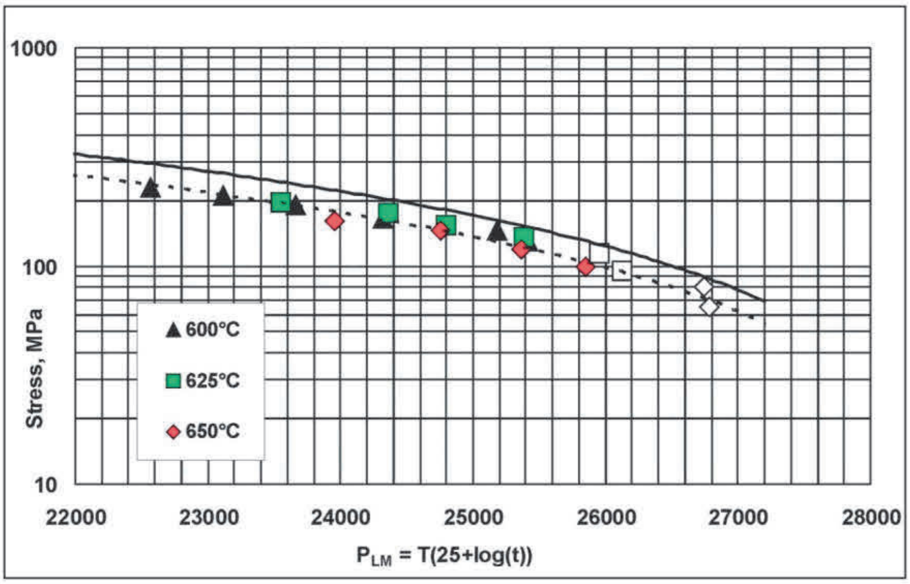

Figure 4 Dependence of stress on the Larson-Miller parameter for the heat B in comparison to the standardized mean values for steel P92

4. CONCLUSION

Delta ferrite contained in steel P92 adversely affects the properties of the steel. The danger lies in the fact, that influence of delta ferrite is largely absent when evaluating short-term strength properties [10]. The presented creep test results show, that the delta ferrite radically degrade creep resistance of steel P92.

Drop of creep properties of P92 steel is probably caused by excessive amount of delta ferrite. Heat A shows higher values of creep elongation and reduction of area than heat B without delta-ferrite. It is supposed, that delta ferrite leads to higher creep plasticity, even if it significantly decreases times to rupture. Influence of delta ferrite on creep resistance of steel P92 and other modern advanced chromium steels should be subject to further research.

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