THE RESISTANCE OF THERMAL SHOCK OF THE 21CrMoV5-7 STEEL

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Abstract

The continuous increase in the demand for electricity, the need to increase the power and of power units, efficiency causes the development and researches of dedicated materials. These materials work in extremely harsh conditions, they must be resistant to high temperatures, sudden changes of temperature and deformation. They are also exposed to fatigue damage both mechanical and thermal. The steel grade presented in this paper is a boiler steel working in temperature ranges 500-600 °C. Important parameters for steels of this type are high temperature mechanical properties. It is also important that a high level of properties is achieved at both elevated and room temperatures. Elements working in such conditions, including the steam turbine armour, are exposed to thermal shock what will be presented in this paper.

Keywords: Thermal shock, high temperature parameters, cracking

1. INTRODUCTION

The dynamic development of technology, in field of energy especially, as well as the increasing requirements entail the need to improve current material [1-7] properties and develop new. Thermal fatigue is a phenomenon studied for about 200 years. Many works have been created on this subject however there is still no clear solution to this problem. There is no best and universal method for assessing how samples subjected to cyclic temperature changes behave. Research on thermal fatigue is a difficult issue, mainly due to the instability of this parameter, which depends on many factors, such as the temperature gradient in which the element works the type of treatment and the chemical composition of the material. Resistance to thermal shock is particularly important in power engineering and welding. A change of temperature several times, based on local heating and cooling during welding, may cause unfavourable changes in structure and properties [7-10].

2. MATERIAL AND METHODOLOGY OF RESEARCH

The tests were carried out on 21CrMoV5-7 steel. This is a boiler grade steel. The scope of the tests included measurements of steel hardness, determination of impact strength at room temperature, 0 ºC, -20 ºC and -40ºC, microstructure investigation and determination of resistance to thermal shocks, which was made at the station designed in the Department of Foundry Engineering Częstochowa University of Technology **Figure 1**. The chemical composition of the tested steel is included in **Table 1**.

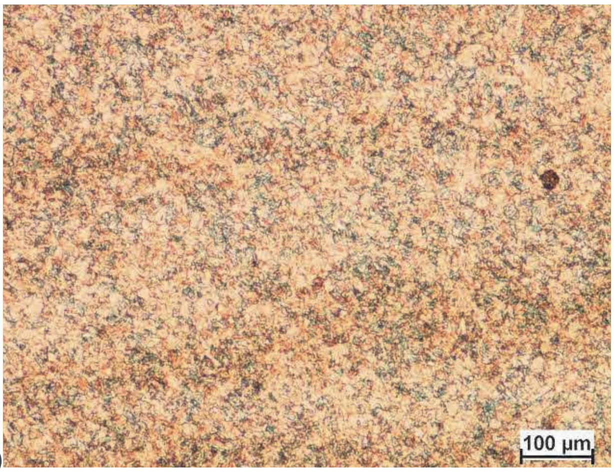
Table 1 Chemical composition of tested material [mass. %]

Element	C	Mn	Si	P	S	Cr	Ni	Cu	Mo	V
	0.194	0.423	0.317	0.008	0.002	1.24	0.168	0.132	1.11	0.256

Figure 1 A device used during tests of thermal shock [6]

3. RESULTS

The analysis of microstructure showed that the tested material is characterized by a very uniform grain size of about 2 to 10 μm, which corresponds to the range of standards normalized to ASTM E 112 (ISO 643: 2003) 10-15. Even distribution of grain size indicates a high degree of material processing, which may indicate that the material was forged or hot-rolled (**Figure 2**). The material hardness was determined using the Vickers method (HV_{30}) and showed a value of 245.

a) 

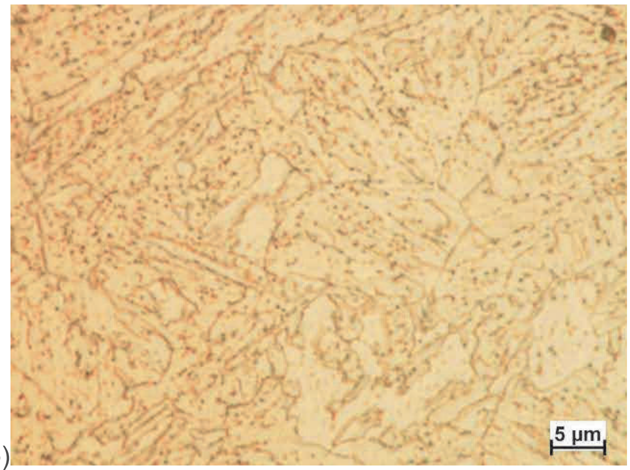
b) 

Figure 2 Microstructure of steel 21CrMoV5-7 a) general view, b) in detail

The next step was to perform impact strength tests, which were carried out at room temperature, 0 ºC, -20 ºC and -40 ºC, and the results are presented in **Table 2**.

Table 2 Breaking energy and impact strength of the 21CrMoV5-7 steel, measured at different temperatures

Temperature [ºC]	**24**	**0**	**-20**	**-40**
Energy of breaking [J]	244	214	205	200
Impact strength [J / cm^2]	305	267.5	256.25	250

On the basis of obtained values of breaking energy was found that the tested material is characterized by very high resistance to dynamic loads (impact strength). It should be emphasized that such high properties achieved even at -40 C guarantee a high safety threshold in real working conditions. In addition, it should be remembered that the material was analysed in the initial state not heat treated. On the basis of the comparative criterion derived from the PN-EN ISO 148-1 standard, it was found that each of the breakthroughs is characterized by ductile fracture, **Figure 3**.

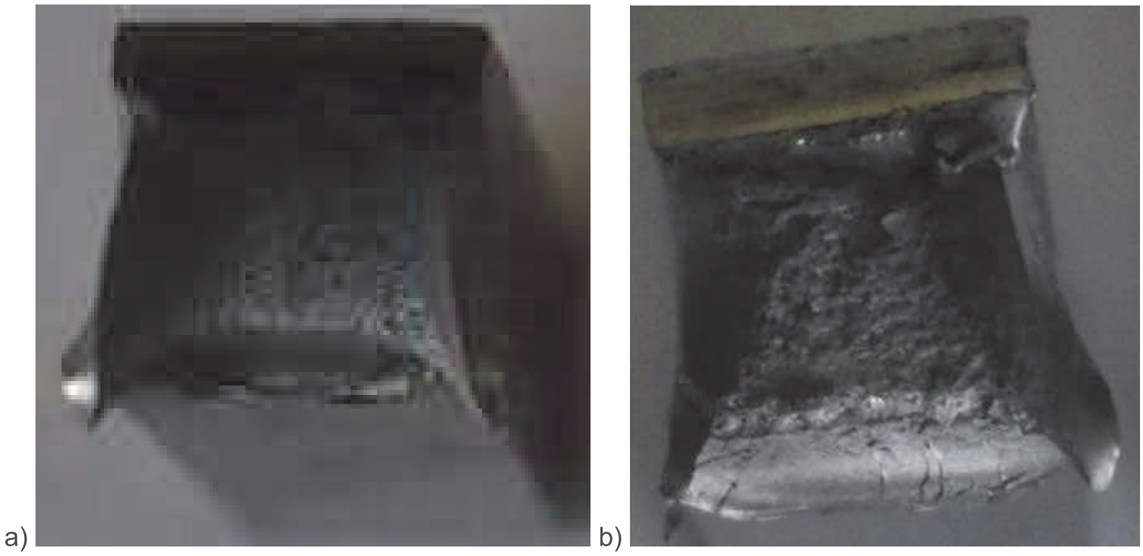


Figure 3 Breakthrough of the 21CrMoV5-7 steel sample a) room temperature (24 °C) b) at -40 °C

The reasons for high impact strength and ductility of the material have to be found in a high degree of throughput, uniform grain size and fine, occurring in the entire volume of carbide precipitation, **Figure 2b**.

To determine the resistance of 21CrMoV5-7 steel to thermal shocks, a special device was used, designed and built in the Department of Foundry of the Częstochowa University of Technology, enabling repeated heating and cooling of samples. To the tests of determination of the resistance to thermal shocks were used specially made samples, **Figure 4**. The shape of the sample was chosen so as to facilitate initiation of cracks at its sharpened corners.

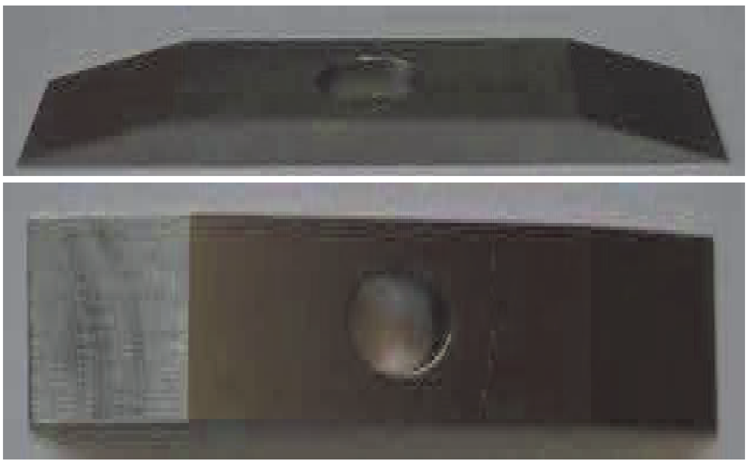


Figure 4 View of samples for assessing heat shock resistance

After heating the sample to a given temperature (measured with the use of a pyrometer), the samples was turned over by 180°, so that the side heated up to 500°C was immersed in water (at 23 °C) and cooled. The number of cycles was measured by means of a counter. The work involved 5 series each about 400 cycles

(200 cycles for each side of the sample). The time of heating the sample to the set temperature (500 °C) was in each case 13 seconds, than the sample was turned over by 180° and cooled in water. In series 1, 420 cycles were performed, after the series 2 the sample was subjected to 840 heat shocks, after the series of 3-1260, and after the series of 4-1680. After this series, first cracks were observed, however the sample was subjected to one more series of 380 cycles. **Figure 5** shows the appearance of samples after 1 series after 4 and after the series 5. After each series, the samples were evaluated using a macroscope and the results obtained are shown in **Figures 6 - 9**.

a)


b)


Figure 5 The view of samples a) after 1 series, b) after 5 series

Figure 6 Macroscopic view of the sample surface after 1 series heat shock

Figure 7 Macroscopic view of the sample surface after 4 series heat shock, marked crack of material

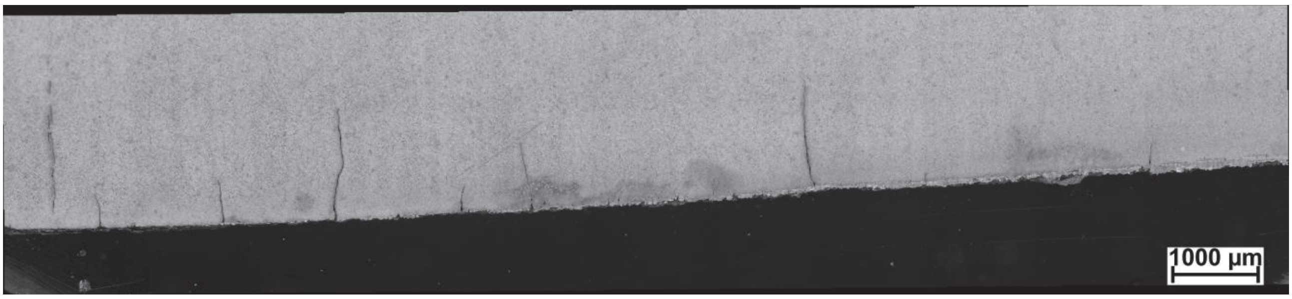


Figure 8 A macroscopic view of the sample surface after 5 series heat shock area about 153 x 3 mm

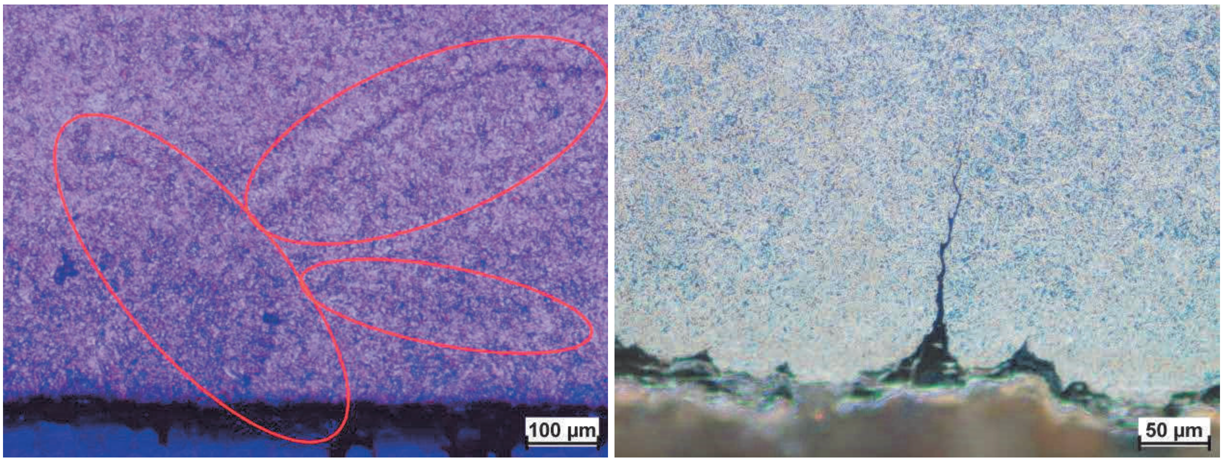


Figure 9 Examples of surface cracking of the test sample after 5 series of heat shock

Performed heat shock resistance tests showed that the tested material is characterized by high resistance to heat shocks. Cooling from around 530 ºC to 23 ºC in about 1- 2 seconds, or from 507-251 ºC / s should be a destructive factor. The shape of the sample with the pointed tip should also affect the acceleration of destruction in this area. As shown by the tests carried out only repeated cooling and heating led to the appearance of cracks. The first cracks were observed after a series 4 of 1660 cycles. After the end of series 5, an increase in the number of cracks was observed. As the research indicates, the material is also characterized by high resistance to thermal fatigue, as evidenced by the length of cracks ranging from about 3 to 7.5 mm.

4. CONCLUSION

The material for testing was 21CrMoV5-7 steel from the type of boiler steel intended for operation at elevated temperatures (up to 600°C, however, on steam turbines this temperature is around 530 °C), dedicated to the professional power industry and resistant to deformation. The carried out research allowed formulate the following conclusions:

1) High impact strength is the result of a high degree of processing, fine, uniformly distributed grain and carbide precipitates.
2) Uniform hardness, maintained at around 246 HV_{30}, guarantees uniformity of the tested mechanical properties.
3) High impact strength, at -40 ºC up to 200 J / cm^2, testifies with a huge reserve of durability for dynamic destruction determined by the energy of breaking, because the tested material is not intended to work in such conditions.
4) High resistance to heat shocks has been confirmed in experimental studies.
5) An additional parameter specified in the above work was the resistance to thermal fatigue, because the first cracks occurred only after fourth series of heat shock (840 cycles for each side).

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