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THE EFFECT OF OPERATING CONDITIONS ON SERVICE BEHAVIOUR OF HIGH ALLOYED STEEL X20

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ABSTRACT
In the present paper, experimental investigations have included the effect of operating conditions (time and temperature of operation) on impact and fracture mechanics properties of base metal, high alloyed steel X20 CrMoV 12-1 (X20). The effect of operating conditions was analysed by testing new material and material that had already been in service for 116000 hours. The values of critical stress intensity factor, K_{Ic}, an important parameter for assessment of the steam lines efficiency was analysed at room and operating temperature. The results obtained and their analysis represent a practical contribution to the assessment of behaviour high alloy steel X20, under impact loading, aimed at revitalisation and prolongation of service life of thermal power plants components, made of high alloy steels operating at elevated temperatures.
Keywords: High alloyed steel X20, impact energy, fracture toughness

1. INTRODUCTION
Some components of process equipment in thermal power plants, operating at elevated temperatures, are critical due to service conditions, particularly after long service period, exceeding the accepted nominal service life. Experienced failures of these components endangered not only human lives and safe operation of a plant, but affected the environment, too. In order to identify the quality and reliability of the material exposed to the effects of elevated temperatures in thermal power plants, mechanical properties of X20 steel were tested. This and similar steels of different manufacturers are largely built into steam lines of thermal plants of Electric Power Industry of ex. Yugoslavia country [1].
The effect of operating conditions (operating time and temperature) on impact and fracture mechanics properties of base metal, steel X20, designed for vital components of thermal power plant - steam lines has been analysed by testing new material and material after service of 116000 hours. Performed investigation at room and operating temperatures of new and used high alloy steel X20 included testing of impact properties, using instrumented Charpy machine (Charpy V-notch test), and critical stress-intensity factor, K_{Ic}, as an important parameter of fracture mechanics.
The results obtained by testing and their analysis should provide a practical contribution to assessment of quality of X20 steel, aimed at revitalisation and extension of service life of vital components in thermal power plants made of high alloy steel for elevated temperatures.

2. MATERIAL

For assessment of the effect of operating time and temperature on impact and fracture mechanics properties of base metal, steel X20, samples of new pipe (*N*) and a pipe that had been in service for approx. 116000 hours (*U*) were available. Both samples were the pipes ∅450 x 50 mm. Chemical compositions of tested pipes are given in Tab. 1 [2].

Table 1: Chemical composition of tested pipe samples [2]

Charge No.	Chemical composition, mass %								
	C	Si	Mn	P	S	Cr	Mo	Ni	V
N	0,21	0,27	0,563	0,017	0,006	11,70	1,019	0,601	0,310
U	0,22	0,31	0,539	0.019	0,005	11,36	1,033	0,551	0,314

The specimens were sampled from the longitudinal direction. The notches on the specimens for determination of impact properties were directed width upward, while the notches on the specimens for fracture mechanics were longitudinal to the pipe longitudinal direction.

3. TEST RESULTS

Impact testing of the base-metal (BM) specimens was conducted according to the standard ASTM E23-02 [3], using the Charpy machine instrumented with oscilloscope. Two types of diagrams were obtained, load vs. time and energy vs. time, with the values of crack-initiation energy, A_I, and crack-propagation energy, A_p, as integral components of total impact energy, as the indicator of the material toughness. Typical diagrams force vs. time and energy vs. time obtained by Charpy testing of specimens taken from new pipe for different testing temperatures are given in Figs. 1and 2 for illustration.

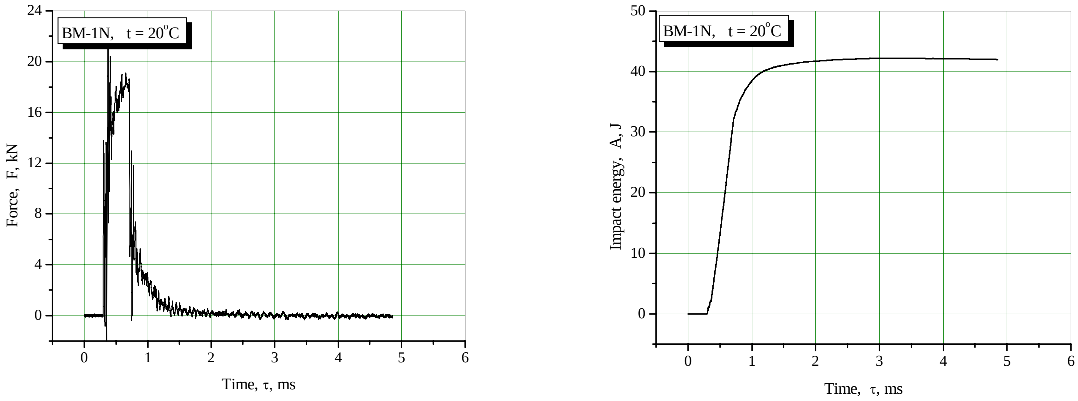

Figure 1. Diagrams obtained by Charpy impact testing at room temperature [2]

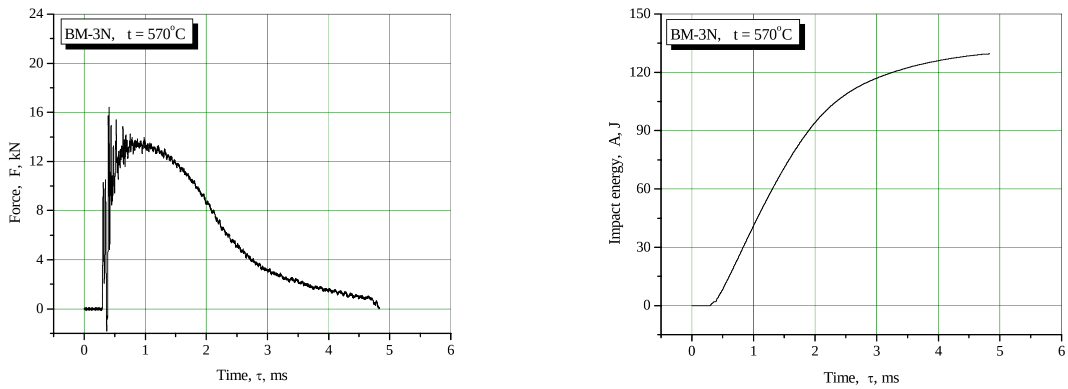

Figure 2. Diagrams obtained by Charpy impact testing at 570°C [2]

The dependence of impact energy, A_t, of new pipes steel X20, on testing temperature is given in Fig. 3. Total impact energy is divided into crack-initiation energy, A_I, and crack-propagation energy, A_p, and presented for new pipe (*N*) in Fig. 4.

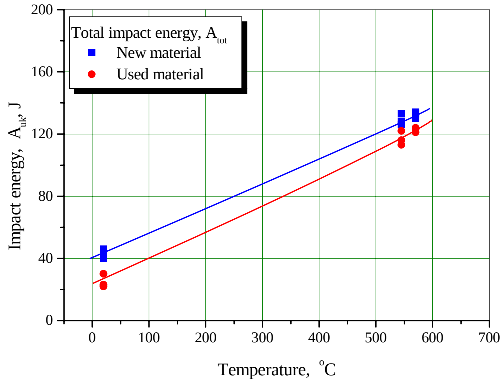

Figure 3. Dependence of impact energy, A_t, of new and used pipes steel X20, on testing temp. [2]

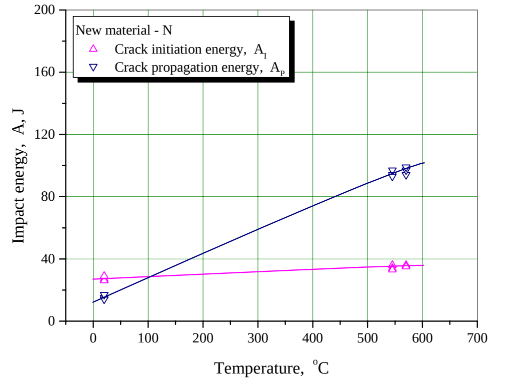

Figure 4: Fraction of crack-initiation energy, A_I, and crack-propagation energy, A_p, for new steel(N) [2]

Critical value of stress-intensity factor, K_{Ic}, was obtained by applying the single-specimen compliance method, by successive loading-unloading cycles. Fracture toughness testing had been performed using three-points bend specimens (SEN-B), and compact tension specimens (CT), Specimen geometry was defined to the standard ASTM E1820 [4]. Three-point bend (SEN-B) specimens were tested at room temperature. Due to available equipment, at operating temperature (540°C and 570°C) only CT specimens of adopted size could be tested [5, 6]. From the relations force, *F,* – crack mouth opening displacement (*CMOD*), *δ,* the diagrams *J* integral vs. crack extension *Δa* were constructed and presented for the specimen tested at room temperature in Fig. 5, and at 570°C in Fig. 6.

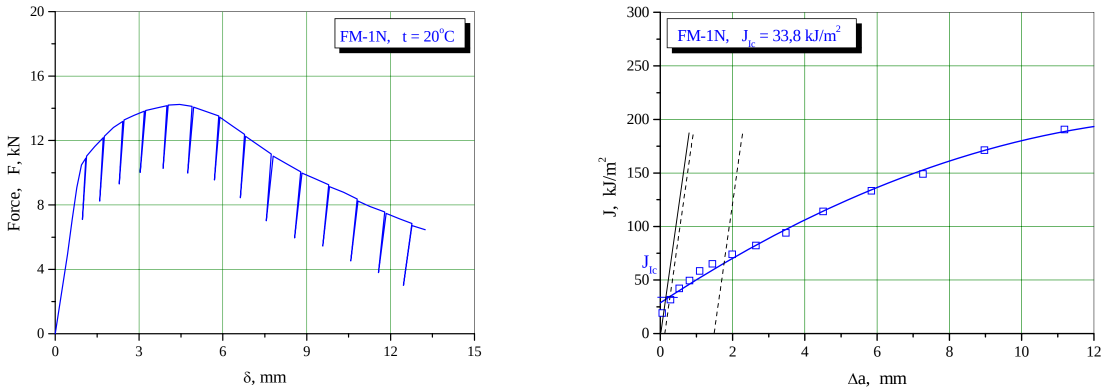

Figure 5. Diagrams F-δ and J-Δa at room temperatures [2]

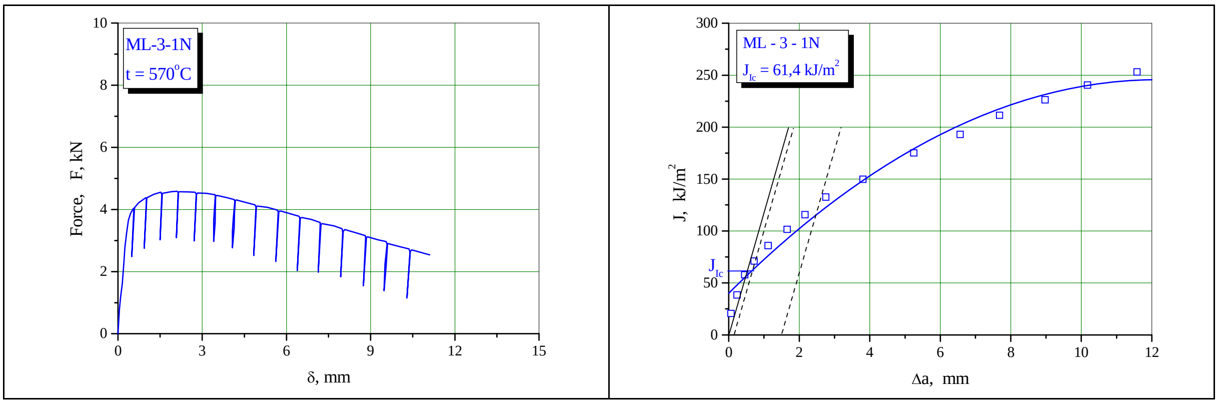

Figure 6. Diagrams F-δ and J-Δa at 570°C [2]

The dependence of critical stress-intensity factor, K_{Ic}, obtained via J_{Ic} integral testing on temperature is given in Fig. 7. It should be mentioned that in calculation of plane-strain fracture toughness, K_{Ic}, one value of Young modulus was used at room temperature (210 GPa), and another at elevated temperatures (175 GPa at 545°C and 570°C).

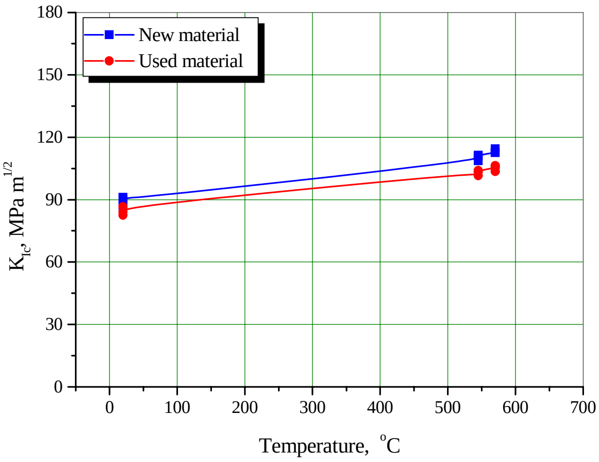

Figure 7. Variation of K_{Ic} value depending on testing temperature for new and used steel X20 [2]

4. THE ANALYSIS OF RESULTS

Total impact energy, A_t, increases with the increase of temperature and reaches the peak value at operating temperature of 570°C. The values of crack-initiation A_I, and crack-propagation, A_p, energy depend strongly on temperature, Fig. 4. At elevated temperatures their ratio varies, and the fraction of crack-propagation energy is about 2.5 times greater than that of crack-initiation energy, exhibiting typical ductile behaviour.

The values of critical stress-intensity factor, K_{Ic}, increase with temperature increase, reaching the peak value at operating temperature of 70°C, Fig. 7. The service time of 116000 hours affected decreasing the values of K_{Ic}.

5. CONCLUSIONS

Obtained test results are a practical contribution to assessment of quality of new and used material, steel X20, regarding possible operating life extension. Following conclusions can be derived:

- Total impact energy, A_t, increases with temperature increase and reach the peak value at operating temperature of 570°C. The same effect is found for energy components, for crack-initiation and for crack-propagation, as well as for deflection. Operating time affects only slightly total impact energy.
- Critical stress-intensity factor, K_{Ic}, increases with temperature increase, reaching the peak value at operating temperature of 570°C. The service period of 116000 hours caused only slight decrease of K_{Ic}, but this is not of prime importance for next service.

6. REFERENCES

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