INVESTIGATION OF BOILER STEEL MICROSTRUCTURE AFTER CREEP FRACTURE

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Macro and micro structures as well as the characteristics of fracture features of simple boiler steel were investigated. Welded boiler steel joint with high alloyed heat resistance steel and with low alloyed steel as a filler material was exposed to the service conditions of heat resistance steel, i.e. working temperature was 540°C and working pressure 180 bar. In high parameter working conditions, after about 20.000h, the complete fracture occurred. Welded joint, from the side of boiler steel, totally failed after the crack propagation through the heat affected zone (HAZ). After investigation by optical microscopy and scanning electron microscopy, as well as mechanical properties, it was obtained that the creep fracture was taking place. Creep process was followed by extensive deformation and the dimension changes of the observed parts.

INTRODUCTION

All fossil power plant components, as well as pipeline elements, are constructed in that manner so they can fulfill exploitation parameters anticipated by project. However, if working parameters emerge from projected limits, there can be a significant influence on the reliability and service life of the pipeline element or any other fossil power plant component. In exceeded service parameters (t,σ) there can be a rapid material softening, and in this case, pipeline system exhaustion and decrease of working parameters, which is a direct creep consequence. Creep process evolution is followed by an extensive plastic deformation, providing that the service life is completely exhausted when the dimension of deformation, at certain creep velocity, reach critical value (1,2). It is well known from literature (1-3) that the creep is occurring in three different stadiums, where are the first and second stadium in

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a structural view characterized with intensive dislocation reaction occurrence, what is consequencing with strengthening and recovering, respectively. In the third creep stadium irrecoverable structural changes are happening and they are resulting in carbide sferoidisation, as well as in micropores and cracks. Aim of this paper was investigation of damage appearance in plain boiler steel caused by disadvantageous service parameters.

BACKGROUND

On the connection of the overheated steam pipeline, made of X20CrMoV121 steel, and the valve chamber, plain boiler steel of the St45.8 type was incorporated instead (that was not known until chemical composition was verified), Figure 1. As a filler material CM2-IG electrode was used for a root pass, and E-V329 electrode for all other passes. Welding parameters, complete technology and filler material choice were selected according to the characteristics of low carbon low alloyed steel of the 14MoV63 type. After 19710 h in exploitation and under the working parameters at T=540^{o}C and P=180 bar, catastrophic failure occurred. Failure take place in the inlet pipe area very close to the assembly weld. Inlet pipe is significantly deformed (ϕ1=338/237 after failure related to the nominal diameter, ϕ=330/220) with variable gap between inlet pipe and weld after failure, and it's value goes up to 5mm, Figure 2 (a,b), measured from outer circumference,. i.e. up to 8mm on the inner one. During the failure analysis, all possible investigation techniques are applied, but in this paper only the results of chemical analysis and metallography are presented.

Chemical analysis: For spectroscopic chemical analysis specimens were taken from both base material (BM1 and BM2), as well as from the weld area, especially from the root (WR) and from the weld midst (WM). Obtained results are listed in Table 1. It is obvious from the presented results that the plain carbon steel of common ferrite-pearlite class is welded by low alloyed electrode as a filler material together with high alloyed heat resistant steel of martensite type.

TABLE 1 - Chemical composition

REGION	CHEMICAL COMPOSITION IN % Wt								ACCORD. TO DIN
	C	Si	Mn	Cr	Ni	Mo	V	Cu	
BM1	0.20	0.34	0.65	11.44	0.548	0.99	0.132	0.082	X20CrMoV121
BM2	0.22	0.33	0.69	0.149	0.242	0.041	–	0.082	St. 45.8
WR	0.06	0.3	0.863	4.66	–	1.19	–	–	~ CM-IG
WM	0.14	0.3	0.59	3.68	–	0.986	–	–	E-V 239

Optical microscopy: Specimens for metallographic analysis are taken from the fractured area. Obtained structures are shown in Fig. 3-7. Figure 3 presents structure array from the plain carbon steel side, beginning from fracture surface, following direction to the valve chamber. Regarding that the fracture occurred on the whole pipe circumference, mainly through the overheating area in HAZ, it isn't possible to observe it's structure because it is completely destroyed during burning. Therefore, the first visible area near the fracture is fine grained normalized HAZ area, Figures 3a, 4. Structure is of the ferrite type with coagulated carbides along the grain boundaries, pores and grain boundaries cracks. Transition area between normalized HAZ zone and plain carbon steel base material is shown on Figures 3b and 5. Basic structure in both area is of ferrite type with coagulated carbides along the grain boundaries and significant boundaries damages. Further to the valve chamber plain boiler steel base material structure is observed, Figures 3c and 6, which are defining the starting structure of ferrite-pearlite type. Namely, processes of sferoidisation and carbide coagulation are taking places, but there are still some visible areas of former pearlite islands, but with destructed structure. Beside, pores appear and along the grain boundaries and in the grains. Figures 3d and 6 are presenting the base material microstructure with not completely destroyed pearlite structure and creep elements, too.

DISCUSSION

On the basis of the obtained data and considering disadvantageous exploitation parameters, it is obvious that in the investigated case fracture occurred as a creep consequence. Because of the unfavorable welding parameters and technologies, HAZ of the plain boiler steel suffered hardest structural changes, therefore it is the weakest place in the whole system.

Because of the well known transformation processes which take place in pipeline steel, regarding time and temperature, lower critical exploitation temperature limit (1-3) must be higher then the working temperature of that element - in contrary, structural changes which are unfavorable for mechanical properties are occurring. Regarding this, implemented boiler steel was exposed for about 60 degrees higher temperature (545^{o}C) then his lower critical exploitation limit(480^{o}C), thereby resulting in untimely structural changes. These structural changes, because of the temperature increment, occurred promptly, so fracture happened after relatively short period.

In general, after acting of static load during long period at elevated temperatures, many structural transformations, superposing each other, occurred in investigated steel: sferoidisation of lamelar cementite and its segregation along grain boundaries which is happening with noticeable rate over 480^{o}C - this structural process is influencing on decrease of all relevant mechanical properties, as well as on creep rate increase; nucleation of new ferrite grains after prolonged period, because service temperature of this steel drops in recrystallization area; dislocation rearrangement, decrease of dislocation density, considerable increase of vacancies, what is the consequence of combined stress and elevated temperature action; micropores forming, because of previously generated vacancies and their segregation along the grain boundaries; microcracks and cracks along the grain boundaries as a consequence of pores fusion.

Comparison of particular structural regions, Figures 4-7, and observed creep gradation inevitably inflicts one more notice. Creep process, with its visible characteristics, is completely finished in areas where complete disintegration of pearlite and coagulation of carbides along the grain boundaries occurred, Figures 4 and 5. In regions where this disintegration process isn't completed, Figure 6 and 7, particular pores and/or pore groups in grain or in grain boundaries, are visible, but without appearance of distinctive cracks.

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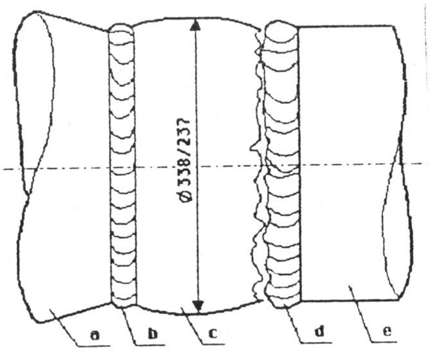

Figure 1. Schematic view of failure position: a) valve chamber b) manufacturing weld, c) append pipe, St 45.8 steel d) assembly weld, e) overheated steam pipeline, X20CrMo121 steel

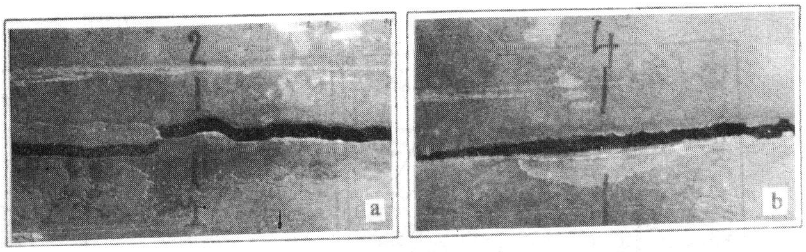

Figure 2 Gap view after failure in positions 2 (a) and 4 (b)

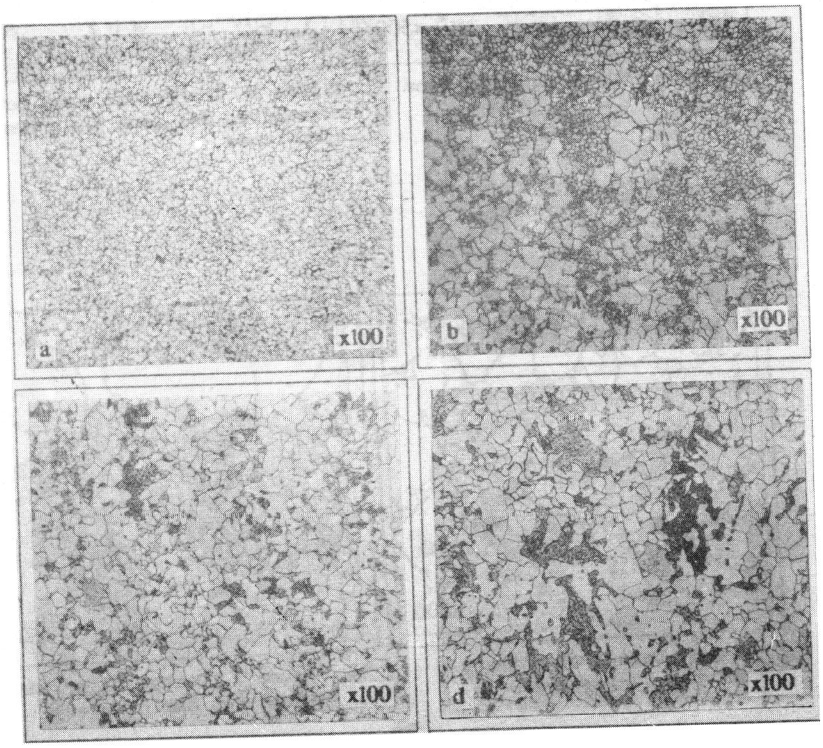

Figure 3 General view of creep gradation

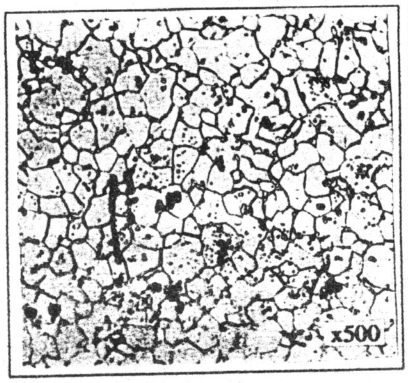

Figure 4 Normalized HAZ zone

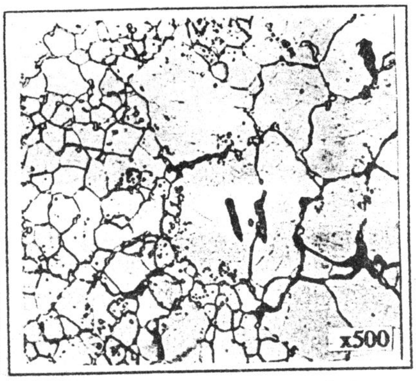

Figure 5 Transition area between normalized HAZ zone and primary structures

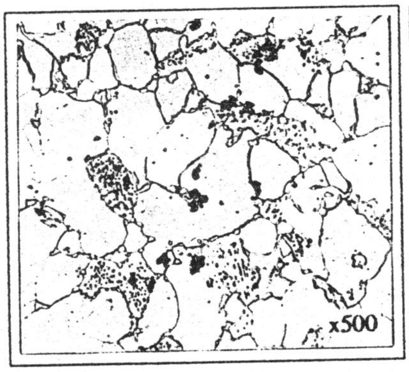

Figure 6 Damage of primary structures during creep

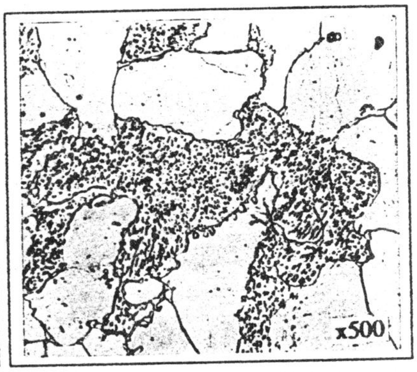

Figure 7 Damage of primary structures during creep