

CORROSION OF Cr-Mn-Ni HEAT-RESISTANT STEEL UNDER THERMOCYCLIC AND MECHANICAL IMPACT IN FURNACE MEDIA

КОРОЗИЯ НА Cr-Mn-Ni ТОПЛОУСТОЙЧИВА СТОМАНА В УСЛОВИЯТА НА ТЕРМОЦИКЛИЧНО И МЕХАНИЧНО ВЪЗДЕЙСТВИЕ В ПЕЩНА СРЕДА

Prof. DSc Dimitar Stavrev¹, Assoc. Prof. Dr Tsanka Dikova²

¹ Technical University of Varna, Bulgaria

² Faculty of Dental Medicine, Medical University of Varna, Bulgaria

Abstract: This research aims investigation of the structural changes of austenite-ferrite steel 105MA (1.4892) subjected to the exploitation impact in the cement furnace. The chains were made of the investigated steel, working in the furnace high temperature zone. Their function is to transport and dry up the technological slurry (37% water) in temperatures 600-900°C. The frequency of the thermal and mechanical loading cycles of the chains corresponds to the furnace rotation velocity of 1,3 oscillations per minute. At the end of the exploitation period (2880 hours continuous work) the technological regime's aberrations was established: the gases temperature reaches 1050°C, while the water in slurry was 55%. The macro- and microstructural analysis shows decreasing of the chains segments' cross sections with about 30% due to the corrosion and the slurry mechanical influence. The initial austenite structure contains ferrite-carbide streaks uniformly distributed along the grains boundaries. As a result of the heat impact with the temperature amplitude above 700°C the structure undergoes recrystallization transformations. The troostite zones decrease because of the increasing the alpha, sigma and carbide phases quantity. The active corrosion begins with pit character. Its development is intercrystalline, attacking at first the phases mentioned above. This process is followed by corrosion-fatigue cracks which branch out in their tip and propagate transcrystalline. They grow mainly along the chain segments' axes in correspondence with the tensile cyclic mechanical loading. The opened cracks fill with the corrosion products and slurry thus accelerating their propagation in thermo-cyclic loading leading to the totally chains destroying.

KEYWORDS: Cr-Mn-Ni HEAT RESISTANT STEEL, CORROSION, CEMENT FURNACE ENVIRONMENT

1. Introduction

The corrosion and heat-resistant steels and alloys were developed and used in the beginning of the last century (1912) in England. The chromium (13% Cr) and chromium-nickel (12% Cr, 8% Ni) steels were the first of this type [1]. As a result of theoretical investigations and the results of practical experience wide range of alloyed ferritic, austenitic, austenitic-ferritic, austenitic-martensitic and martensitic steels and alloys were created [2,3,4]. The structural type of the steels is determined by the Schaeffler's monogram [5,6]. Their corrosion resistance in different media, loadings and temperatures is mainly due to the alloying elements Cr and Ni [7,8]. According to the classic theory of the corrosion processes and the practical results of the corrosion damage [9,10], the austenitic type steels are used in installations, working in conditions of gas corrosion in high temperatures. Kinetics of phase's formation of chromium [10] and nickel-chromium [11] steels in such conditions was theoretically and

experimentally investigated. Their significant corrosion resistance in temperatures up to 750-800°C is well-known. Using of Mn as alloying element instead of the expensive Ni [12] can decrease its quantity while the exploitation structure and properties are saved.

The data for the behavior of Cr-Mn-Ni steels in high temperatures, mechanical impact and real furnace media are relatively scarce in the literature. The aim of this work is to investigate the corrosion fatigue damage of steel 105NA (1.4598) as a material for chains of cement furnace.

2. Experimental methods

2.1 Exploitation conditions

In the chain zone of furnace as part of the technological line for cement production, Cr-Mn-Ni steel chains have been mounted with the purpose of drying the input raw-material grout having the following basic parameters (Table 1).

The period of operation was about 2880 hours at continuous mode of operation. The following deviations in technology were established at the end of the exploitation period: grout humidity – 55% and gas temperature in the area – 1050 °C.

The material in the chain links was 105MA DIN14872-93 (1.4892) with chemical composition as per delivery specification, shown in Table 2.

2.2 Samples' preparing and investigation

Three objects of study have been selected at random selection: a new chain link before mounting, without operational impact, and two chain links after operation.

The samples cut transversely and along the link axes, were

Table 1
Basic construction-technological parameters.

№	Parameters	Unit	Value
1	Furnace diameter	mm	5000
2	Chain length	mm	3240
3	Chain links	bp.	27
4	Outer dimension by link width	mm	100
5	Frequency of furnace revolution	min ⁻¹	1,3
6	Hanging points per ring	bp.	88
7	Damaged rings in the area	bp.	8
8	Distance between the points of hanging	mm	178
9	Gas temperature in the area	°C	900
10	Grout temperature in the area	°C	600
11	Grout humidity	%	37

Table 2
Chemical composition of the steel investigated 105MA (1.4892), %.

Chemical element	C	Si	Mn	P	S	Cr	Ni	Mo
Delivery specification	0,2-0,3	≤1	8,0-10,0	<0,045	<0,015	19,0-21,0	3,5-4,5	-
Chain link	0,161	0,690	7,630	0,032	0,010	19,644	4,04	0,163



Fig.1 Chain links of 105NA (1.4892) steel: 1 – a new before mounting, 2 – link in operation, 3 – link destroyed after operation.

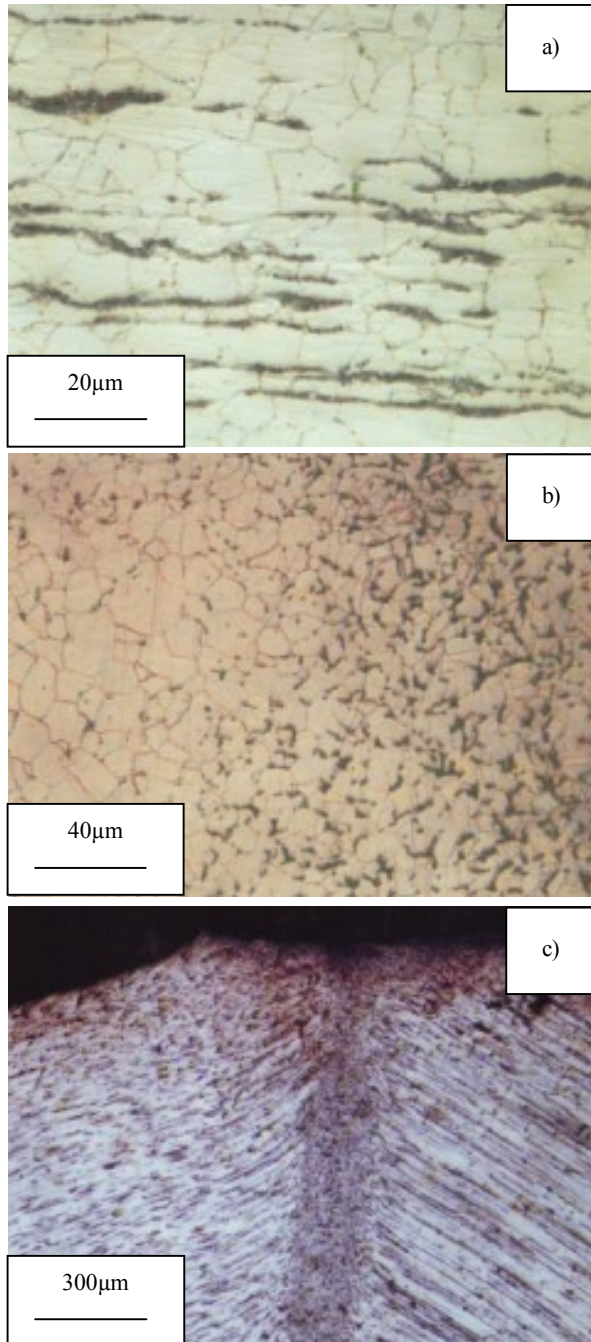


Fig.2 Microstructure of a new chain link: sample along the link axe – a), sample transversal to the link axe – b) and welding zone – c).

preliminary prepared by grinding and polishing. The spectral analysis was done by SPECTROMAX IMXM3 analyzer. The metallographic and fractal analysis were carried out by optical microscopies „Technival-2 Sitoval 2 – CZ – Jena“, „Neophot 32“ and „Epityp“.

3. Results and analysis

3.1. Chemical composition of the steel investigated

The chemical composition of the investigated chain link is shown in the Table 2.

The Chrome equivalent is

$$Cr_{eq} = Cr + Mo + 1,5xSi + 0,5xNb = 20,83\% \quad (1)$$

The Nickel equivalent is

$$Ni_{eq} = Ni + 30xC + 0,5xMn = 12,68\% \quad (2)$$

According to the nomogram classification the steel has two-phase structure – austenite + 5-10% ferrite, ignoring the presence of carbides, formed as a result of the carbon content. The presence of carbon testifies to the existence of ferrite-carbide structures with pearlite-sorbite-troostite morphology. The comparative analysis of the alloying elements content in 105MA steel and the content in the elements obtained during the study of the specimen taken for chemical analysis shows that the links material corresponds to that stated in the delivery specification with the insignificant deflections in C and Mn content.

3.2 Microstructure and fractal analysis

No defects and roughnesses on the outer surface of the new chain link (Fig. 1) can be observed. The texture in direction of the plastic deformation (Fig. 2-a), the structural non-homogeneity of the welding area in comparison with the remaining part of the link (Fig.2-c), as well as the differences in the microstructure of certain parts of the section (Fig.2-b) testify that the chains have not undergone heat treatment (quenching and tempering) to achieve homogeneous structure.

Due to active corrosion the cross section of the links in operation has decreased by 30%. Areas with non-interrupted or many interrupted cracks are observed on the outer working surface of the links. The cracks are located mainly across the longitudinal axis of the links under discussion. Apart from these, there are other cracks located either along or at an angle to the axis (Fig.3). Cracks occur mainly at right angles to the longitudinal axis of the link, i.e. in the direction of the tensile work stresses. The cracks fill with corrosive products and grout which additionally accelerates the speed of crack propagation. Corrosion-fatigue cracks, starting on the surface (Fig.4-a), often spread in different directions downwards in depth (Fig. 4-b). In the area of welding seams, corrosion-fatigue cracks also occur and spread, the process not differing from those in the other areas (Fig. 4-c).

The presence of secondary and collective recrystallization of the austenite grains shows that the working temperature of the chain has been at least equal to or greater than that of recrystallization which for Cr-Ni steels varies within 650-700°C. The structures observed in various parts of the cross section of a link in operation are the most typical example of secondary and collective recrystallization. The size of the austenite grains is biggest after collective recrystallization taking place in the areas located immediately at the working surfaces of the links (Fig. 5).

Two important processes are observed after operation: decrease and disappearance of prolonged sorbite-troostite grains which were present in the initial structure. After link operation, the existence of austenite structure (Fig.5) prevails being segregated from secondary

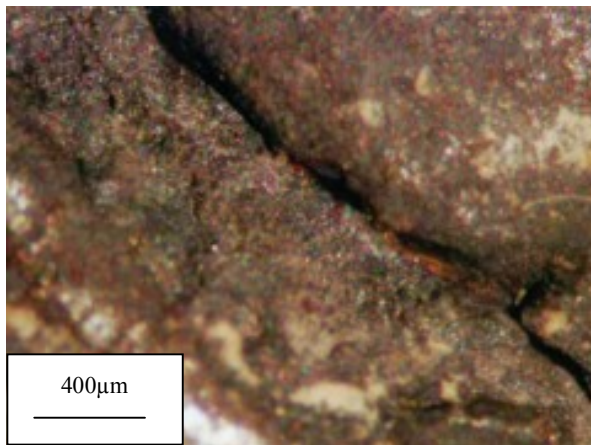


Fig.3 Crack on the surface with direction at an angle to the axis.

phases (α , σ and Fe_3C) mainly at the grain boundaries. The results of the structural investigations do not give grounds for identifying the existence of σ -phase as part of the steel morphology prior to operation.

3.3 Discussion

The chain links are simultaneously subject to 3 types of operational impact – corrosive, thermal and mechanical. These influences are exerted recurrently by means of pulse changes in the factors, the frequency coinciding with that of furnace rotation – 1.3 min^{-1} .

The individual links in a chain are loaded to a different extent. Those located closest to the points of hanging experience the highest mechanical load. It can be assumed that they are thermally loaded to the least since they are closest to the heat removing surface.

Taking into account the presence of water in the grout, the turbulent motion of gases in the furnace and the rotation of the furnace itself, it can be assumed that the corrosive influence of water vapor and furnace gases is the same for all links.

The mechanical, thermal and corrosive loads are de-phased in time. The maximum corrosive impact of furnace gases coincides with the vertical position of the chain when it is streamlined by the former. The maximum of the thermal load is in the second phase of rotation when the chain has been for the longest period of time under the influence of the hot furnace gases, at the same time moving downwards. It can be assumed that the maximum corrosive impact is de-phased with the thermal one by $\frac{1}{2}$ revolution.

It should be noted that the equivalent operation load is equal to low-cycle fatigue behavior under the influence of thermal and mechanical stresses accompanied by corrosive impact of the operation environment.

The structure damage and the successive total destruction may be assumed to have been caused by the simultaneous influence of high-temperature corrosion, mechanical external tensile stresses and internal thermal stresses under cyclic influence.

The destruction has started from the working surface of the links (Fig. 4-a). Corrosive damage has started at subsurface level in the form of pitting (Fig. 5).

Most frequently, the spread of the corrosive subsurface damage coincides in direction with the damage starting on the working surface. The corrosion-fatigue cracks branch off at their very root and spread in an inter-crystal way (Fig. 6-a).

The grout, filling the caverns caused by the surface corrosive damage, along with the iron oxides and the alloying components inside the caverns speeds up their deepening and widening (Fig. 6-b). This process is also deteriorated by the active evaporation of the grout

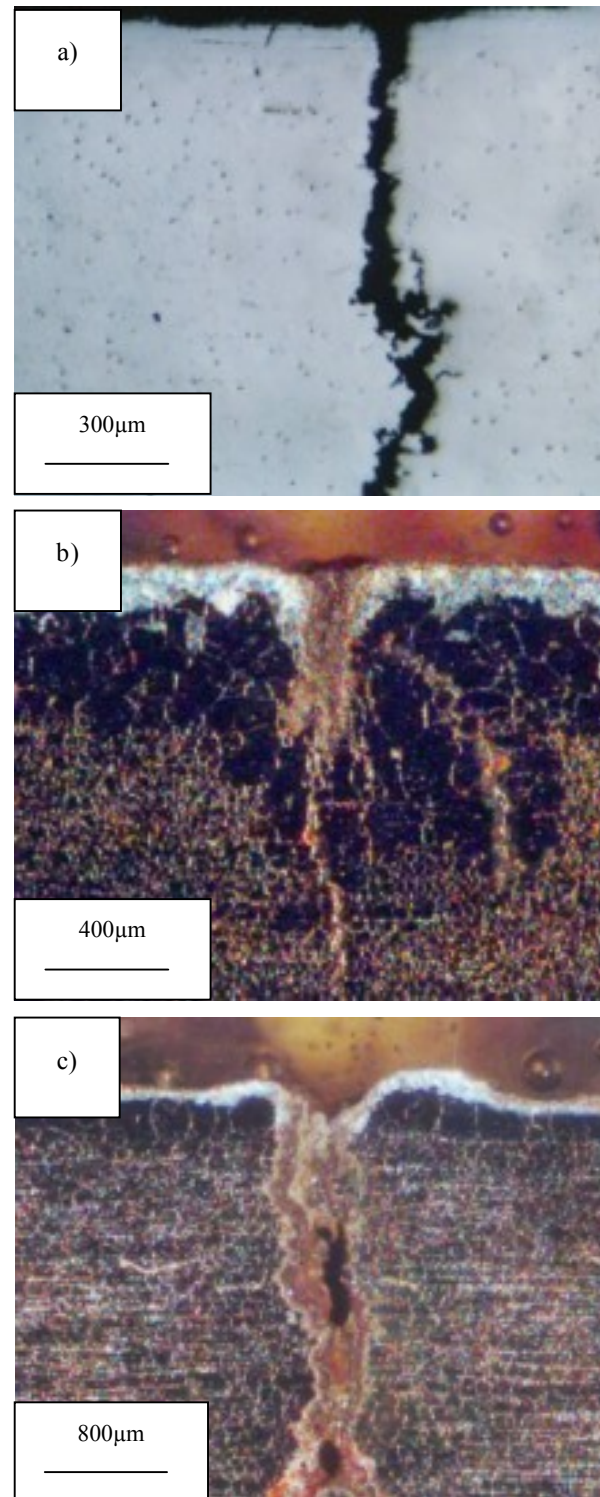


Fig.4 Corrosion fatigue cracks: development from the surface in depth – a) spreading in different directions downwards in depth – b) and crack in the welding zone, transversal to the link axis – c).

filling the cracks and attacking them by additional mechanical and corrosive influence.

Further, the crack widens and deepens rapidly and on reaching the critical dimension of the carrying cross section, a transverse

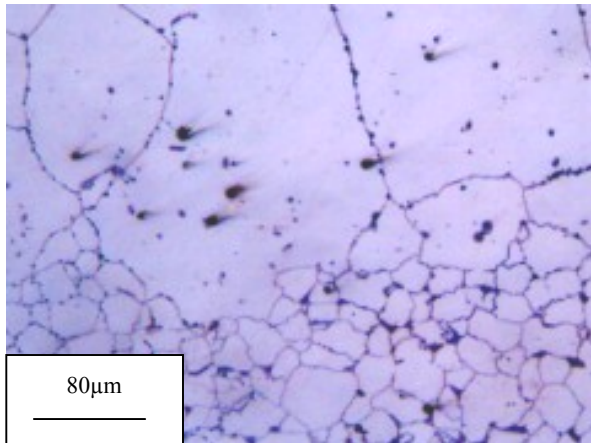


Fig.5 Collective recrystallization, trans- and intercrystal corrosion just below the working surface.

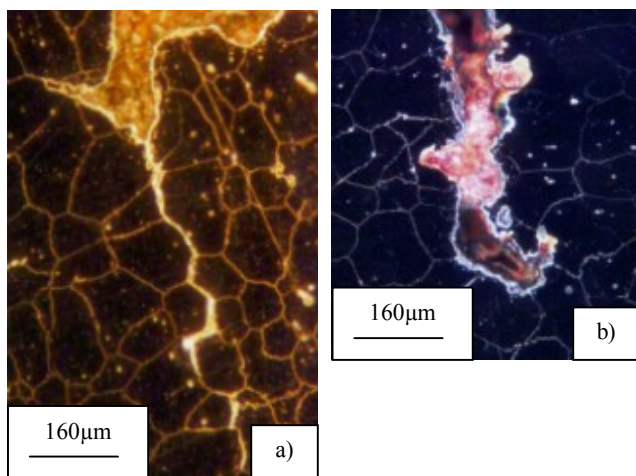


Fig.6 Transcrystal growth of surface corrosion fatigue crack – a) and active corrosion development in depth – b).

destruction of the link takes place, this appearing most frequently around the middle section where tensile stresses are greatest.

4. Conclusions

- The links in operation have suffered considerable surface and deep-structure corrosive impact, about 30% of the structure being destroyed. Areas of corrosive destruction and a great number of cracks starting on the surface in different directions can be observed. The orientation of the cracks is mainly perpendicular to the tensile working stresses along the longitudinal axis of the links.

- The cracks are uninterrupted or with lots of interruptions observed on the working surfaces. They originate from surface corrosion caverns. Upon opening they are filled with corrosive products and grout which significantly accelerate the rate of their propagation. In some cases the corrosion-fracture cracks spread under the surface and branch off in other directions.

- The cracks in the area of the welding seam do not differ in morphology from those in the remaining part of the link with the exception of the areas with less recrystallization.

- During operation the elongated sorbite-troostite grains decrease and disappear. Austenite structure is formed with segregation of secondary phases located mainly around the grain boundaries.

- Areas of active recrystallization can be observed resulting from austenite grain growth strongly expressed on the surface and along the cracks and accompanied by trans- and intercrystal corrosion.

- The existence of areas with secondary and collective recrystallization of the austenite grains testifies to the increased working temperature exceeding the recrystallization of this type of steels. The largest are the grains below the working surface subject to the direct influence of the hot furnace gases and the grout.

- In the process of furnace operation the grains are subject to low-cycle fatigue stress by pulsating thermal and mechanical stresses and high-thermal corrosion resulting from the grout present and the hot gases. The cyclic load corresponds to the furnace revolutions, the thermal and mechanical stresses being de-phased.

- The low-cycle fatigue destruction is the result of the complex action of the operational factors described. It has been accelerated by the exceeding of the technological parameters (gas temperature and grout humidity) violating the operational limits regulations. Upon reaching a critical cross section, part of the links have been destroyed which has been facilitated by the existing impact loads during furnace revolution.

5. References

1. Свистунова Т.В., Шлямнев А.П., *Развитие и применение коррозионно-стойких сталей и сплавов*, МнТОМ, 2010, №7, с. 9-17;
2. ASM Specialty International Society, *Handbook Stainless Steel. The Materials* / V.R. Davis, 1994. 557p.;
3. Шлямнев А.П., Свистунова Т.В., Сорокина Н.А. и др. *Коррозионно-стойкие, жаростойкие и высокопрочные стали и сплавы: Справочник*. М.: Проммет-СПЛАВ, 2008. 332 с.;
4. Арзанасов Б.Н., Макарова В.И., Мухин Г.Г. и др. *Материаловедение* М.: изд-во МГТУ имени Н. Э Баумана, 2003, 648.;
5. Фетисов. Н.Г., Карпман В.М., Матюнин В.С. и др. *Материаловедение и технология металлов*. М.: Высшая школа, 2001. 638 с.;
6. *Werkstoffkunde*. Hrsg. Von H-J. Bargel, G. Schulze, 6 ürearb. Aufl. – Düsseldorf, VDI-verl., 1994, 410 s.;
7. Ульянов Е.А. *Коррозионно-стойкие стали и сплавы: Справочник*. М.: Металлургия. 1991. 253 с.;
8. Шлямнев А.П., *Коррозионно-стойкие стали и сплавы В кн. Новые материалы*. М.: изд-во МИСиС. 2002. С.345-359.;
9. Томашев Н.Д., Чернова Г.П., *Теория коррозии и коррозионно – стойкие конструкционные стали*. М.: Металлургия. 1986, 359с.;
10. Приймак Е.Ю., Грызунов В.И., *Кинетика формирования и роста фаз в оксидном слое стали 30X13 при высоких температурах*. МнТОМ. 2010, №9, С. 22-25.;
11. Приймак Е.Ю., Грызунов В.И., Грызунова Т.И., *Кинетика газовой коррозии высоколегированной аустенитной стали 12X18H10T* // МнТОМ. 2009. №9, С. 21-24.;
12. Митропольская С.Ю., Вичужанин Д.И., Брезовская В.В., Туева Е.А., *Влияние упряго-пластического деформирования на структуру и магнитные свойства высокопрочной коррозионно-стойкой аустенитной стали типа 03X20Al11X7M2* // МнТОМ. 2011. №2. С. 17-21.