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Failure Analysis of the Stacker Crawler Chain Link

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Abstract

Stacker ARs 2000 presents the final link in the system for continuous overburden removal in the open pit mine "Kostolac" – Serbia. Its superstructure leans on three crawlers of the same length, width and height. During the stacker's travel from the erection site to the open pit mine, three crawler chain links fractured, presenting an indication of the problems that were to occur during exploitation. In fact, after only 1000 working hours (about three months), 30 chain links sustained fractures resulting in direct and indirect costs due to the downtime that substantially diminished the effects of the overburden removal system. The goal of the study presented in the paper was to diagnose the cause of chain link breakdown occurrence. Working stresses in the chain link are defined by applying FEM. Experimental investigations define the chemical composition, the tensile properties, the impact toughness and the macro and microhardness. Metallographic examinations are conducted additionally. Based on the results of the numerical-experimental analysis, it can be concluded that chain link breakdown is predominantly caused by (a) substantial deviation of the mechanical properties of the material with respect to those prescribed by the standard and (b) the existence of macro and microcracks in the material structure.

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Keywords: stacker; crawler chain link; failure analysis; FEA; experimental investigation

1. Introduction

Stackers as well as bucket wheel excavators are the key links of the system for overburden digging. In certain cases and in very hard working conditions, their mobility may lead to failures of traveling mechanisms [1-4] and related structures [5]. The mentioned failures can be caused by [6,7]:

- Designing-in defects;
- Manufacturing-in defects;
- Operating-in defects;
- Environment-in defects.

Regardless of the cause, failures of high performance machines, such as stackers, always lead to very high financial losses [8,9]. The superstructure of the stacker ARs 2000, Fig. 1, leans on three crawlers of the same length,

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width and height. During the stacker's journey from the erection site to the open pit mine, three crawler chain links fractured, presenting an indication of the problems that were to occur during exploitation. In fact, after only 1000 working hours (about three months), 30 chain links sustained fractures, Fig. 2.

Basically, the crawler pad structure consists of a chain link and sheet wings which are welded to it, Fig. 3. The chain links are interconnected by cylindrical joints, thus forming a close crawler contour. The driving force is transmitted during the coupling of the chain links with the drive tumbler. The track wheels roll over the chain links Fig. 1. Thus, chain links achieve key functions of the crawler travel gear: the transfer of propulsive forces and all loads on the ground. Due to the highly complex conditions in which they operate, it is of primary importance to make a proper selection of materials, as well as to follow a strict chain links fabrication technology. In the considered case and according to the design documentation, the chain links were supposed to be made from cast steel quality grade G30CrMoV6-4 + QT2 according to the code [10].

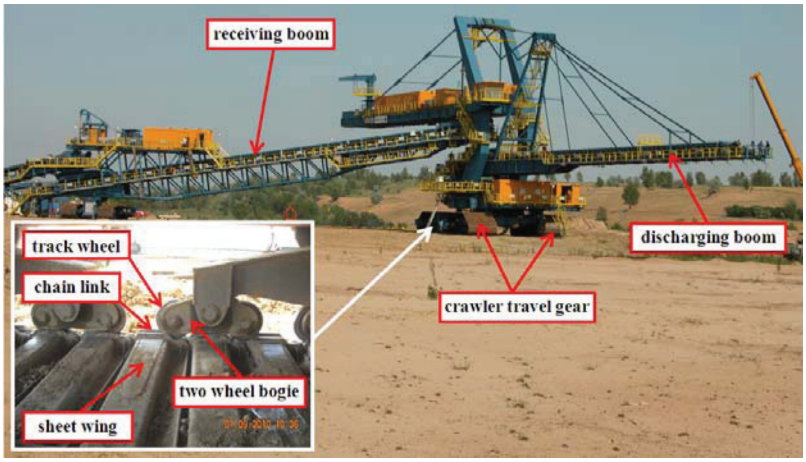

Fig. 1. Stacker ARs 2000

Fig. 2. Fractured (a) female lugs; (b) male lug; (c) chain link body

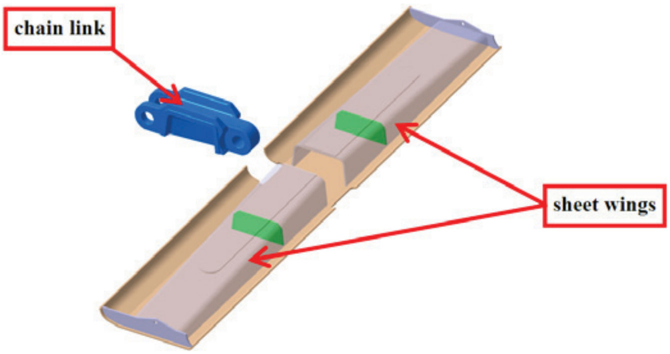

Fig. 3. Basic substructures of the crawler pad

2. Identifying the stress state caused by the external load

The chain link stress state is calculated by applying the linear finite element method (FEM). The 3D model, Fig. 4(a), represents the continuum discretized by the 4-node linear tetrahedron elements [11] in order to create FEM model (425,279 nodes and 1,880,295 elements), Fig. 4(b).

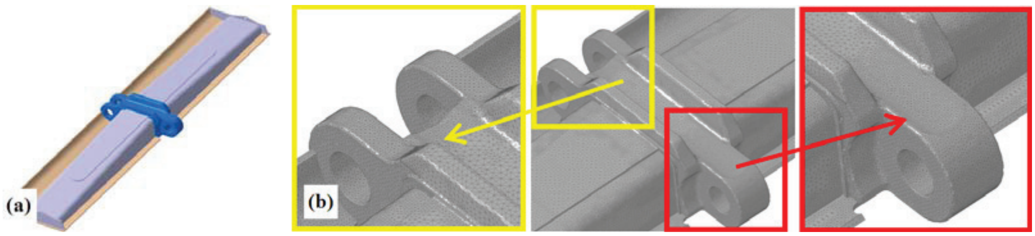

Fig. 4. (a) 3D model of the chain link; (b) detail of FE mesh in fracture zones

The analysis of the external load is performed in accordance with the referenced literature [12,13] and code [14]. Under the action of the relevant working load, Fig. 5(a), the maximum level of stresses in the critical zones does not compromise the integrity of the considered structure, Fig. 5(b,c).

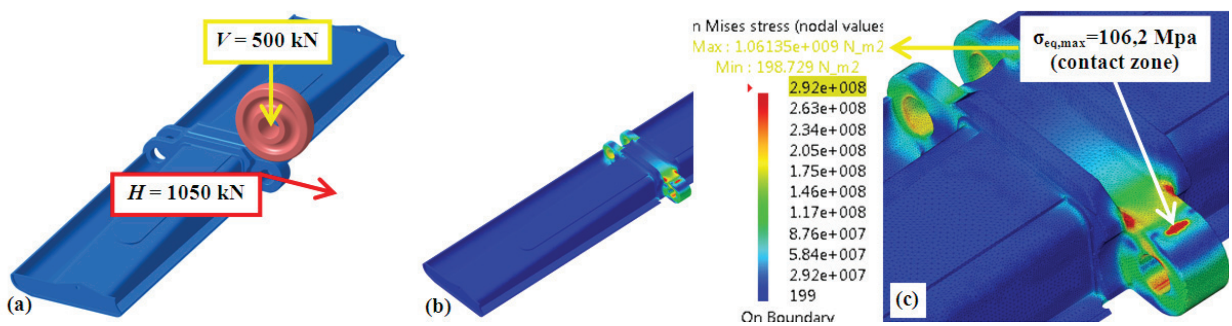

Fig. 5. (a) Relevant working load of the chain link; (b) global distribution of von Misses stresses; (c) von Misses stresses in fracture zones

3. Experimental procedure

Experimental investigations were conducted on specimens made of the chain links' broken parts, Fig. 6.

Fig. 6. Broken part of a chain link

3.1. Chemical composition and mechanical properties

Chemical analysis of the chain link material, Table 1, was conducted by the spectrometric method using the quantometer ARL 360. Comparative analysis of data presented in Tables 1 and 2 leads to the conclusion that the chemical composition of the chain link material meets the requirements of standard [10].

Table 1. Chemical composition of the chain link material

Element	C	Si	S	P	Mn	Ni	Cr	Mo	V	Al
Content (%)	0.339	0.753	0.005	0.003	0.836	0.123	1.638	0.469	0.140	0.141

Table 2. Chemical composition of the prescribed chain link material G30CrMoV6-4 as per [10]

Element	C	Si	S	P	Mn	Cr	Mo	V
Content (%)	0.27-0.34	max. 0.60	max. 0.020	max. 0.025	0.60-1.00	1.30-1.70	0.30-0.50	0.05-0.15

The tensile properties test results [15] showed that the elongation of the chain link material is more than 40% less than the elongation prescribed by standard [10], Tables 3 and 4.

Table 3. Tension test of the chain link material at 22°C

Specimen	σ_{YS} (MPa)	σ_{UTS} (MPa)	Elongation (%)
1	796	923	7.50
2	788	908	7.00

Table 4. Tensile properties of the prescribed chain link material G30CrMoV6-4 as per [10]

σ_{YS} (MPa)	σ_{UTS} (MPa)	Elongation (%)
min. 750	900 - 1100	min. 12

The impact energy ($KV_{300/2}$) of the chain link material is determined according to [16]. It is approximately 2.4 times less than the prescribed one in [10], Table 5.

Table 5. Impact energy of the chain link material

Specimen	Temperature (°C)	$KV_{300/2}$ (J)	Mean value*
1		10.79	
2	- 20	8.83	9.81
3		9.81	
4		13.73	
5	+ 20	13.73	13.08
6		11.77	

*Code DIN EN 10293 prescribed min. 31 J at a temperature of $+20^{0}$C

The Vickers hardness testing method is performed on the sample shown in Fig. 7. The measured values of macrohardness [17] showed irregular dispersion of results at the cross section, Table 6. Microhardness [17] of the surface layer is lower than the microhardness at greater depths, Table 7. Finally, the results of the hardness measurements indicate that the required depth of hardening - 10 mm, according to [18], is not achieved by induction hardening.

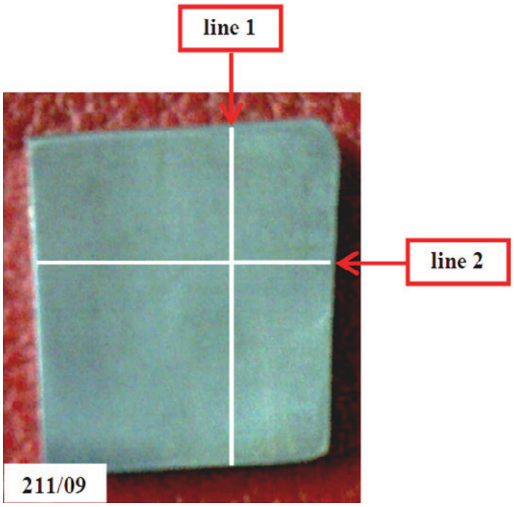

Fig. 7. Macro and microhardness measuring lines

Table 6. Macrohardness (HV5) of the sample with internal tag 211/09 (raster of measuring points 2 mm)

Line 1	321-321-313-310-293-296-299-296-306-306-303-306-310-321-313-321-321-313-321-325-321-321-317-321-321
Line 2	313-310-306-303-303-303-310-313-313-317-313-313-321-321-321-310

Table 6. Microhardness (HV1) of the sample with internal tag 211/09 (raster of measuring points 1 mm)

Line 1	257-269-269-297-297-297-297-305-305-297-297-290
Line 2	290-276-276-283-290-313-305-297-276-321-305-297

3.2. Microstructure testing

The microstructures shown in Fig. 8 are bainite - pearlite with carbide inclusions. Cracks of different lengths are observed as well.

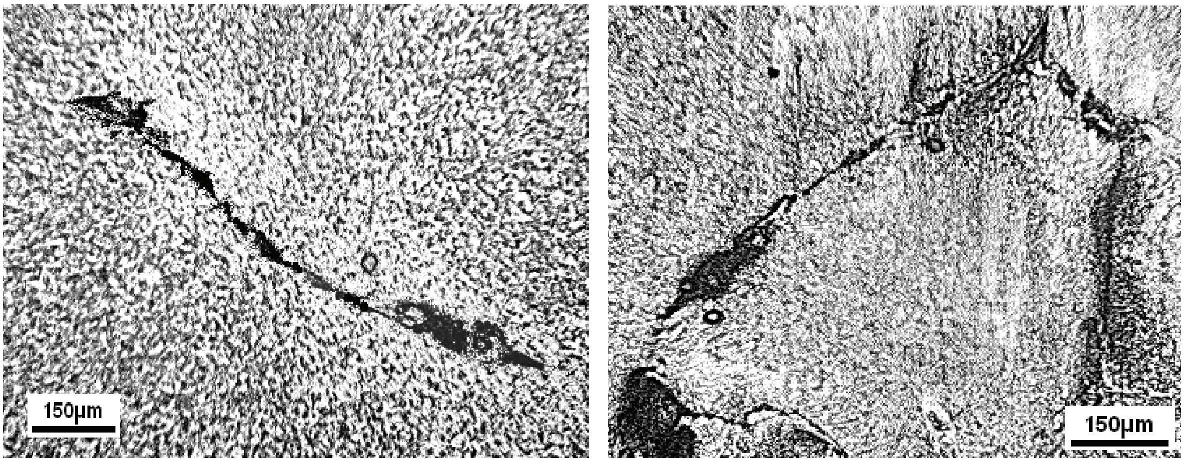

Fig. 8. Bainitic-pearlitic microstructure with carbides and nonmetallic inclusions: (a) macrocrack length of about 0.9 mm; (b) macrocrack length of about 1.5 mm

4. Conclusion

Based on the results of the numerical-experimental analysis, it can be concluded that the chain link breakdown is predominantly caused by:

- Substantial deviation of the mechanical properties of the material with respect to those prescribed by the standard;
- The existence of macro and microcracks in the material structure.

Therefore, the presented failure of the chain link belongs to the class of failures caused by the so-called 'manufacturing-in' defects [6,7].

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