BUCKETS OF THE BUCKET WHEEL EXCAVATORS: FAILURES AND REDESIGN

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Summary: *Design of the buckets of the bucket wheel excavators has to meet the set of the functional requirements imposed by the processes of: (a) soil cutting; (b) filling; (c) transportation of the grabbed soil; (d) emptying. Optimal conduct of each of these processes imposes requirements, which are often in mutual collision. Except functional requirements, bucket structure has to meet, naturally, rigidity as well as strength criterion. During exploitation in harsh working conditions, failures of buckets occur relatively frequently. There are two basic types of bucket failures: structural and technological. In this paper, two bucket structural failures as well as one techologocal bucket failure are presented. Investigations' results pointed out that structural failures are caused by 'design-in' as well 'manufacturing-in' defects. Technological failure of the bucket was also of the 'design-in' type. Besides that, the redesigned buckets' are presented. Exploitation after the reconstruction fully confirmed the validity of the presented reconstruction design.*
Keywords*: bucket wheel excavator, bucket, structural failure, technological failure, redesign.*

1. INTRODUCTION

Generally, there are three basic reasons for any machine or its parts redesign: (a) technological failure when considered object no longer meets technical specifications, but still works; (b) easier maintenance; (c) structural failure of the studied object. The first two reasons are dominantly consequences of design faults, so-called ‘designing-in’ defects, whilst the structural failure, besides already mentioned ‘designing-in’ defects, could be caused by ‘manufacturing-in’ defects, ‘operating-in’ defects and ‘environment-in’ defects as well as the combination of several different causes [1].

Bucket wheel excavators (BWE) are the core of the mechanization system in

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open pit mines. Their exploitation in extremely heavy duty conditions causes the failures of structural parts – plastic deformations, cracks and fractures. Mentioned failures are always followed by financial losses caused by production delays which significantly exceed the financial losses caused by direct material damage.

Design, and analogously redesign, of the buckets of the BWE has to meet the set of the functional requirements imposed by the processes of: soil cutting, filling, transportation of the grabbed soil and emptying. Optimal conduct of each of these processes imposes requirements, which are often in mutual collision. Except functional requirements, bucket structure has to meet, naturally, rigidity as well as strength criterion.

External operational loads are of an outstandingly dynamic and stochastic nature, so that calculated loads are assumptions, in the full sense of the word. And exactly because of that, comparative stress analysis presents an indispensable and inevitable part of the redesign process. The following sections will present a part of research dedicated to two basic types of bucket failures: structural and technological.

2. TECHNOLOGICAL BUCKET FAILURE

Failures of buckets are not always of a ‘‘damage’’ type. They also could be of a ‘‘technological’’ type that means that bucket, or some of its parts, does not perform its function in the manner required. It is interesting to note that ‘‘technological’’ type failures are often not given sufficient attention [1].

When coal is dry, especially during summer, emptying of the BWE O&K SchRs 630 buckets was almost total (≈100%). But during winter, when coal get wet and condensation appears, adherence of small fraction (dust) of excavated material takes place. Layer of adhered material fulfilled almost 50% of bucket volume, which led to drastic reduction of BWE capacity. This technological failure, as well as periodical cracks occurring in the rear side fastening, imposed the necessity of bucket redesign. The basic idea of redesign of the original bucket structure, Fig. 1 (a), was to eliminate bucket back in order to mitigate adherence of the material. Bucket back was replaced with chain mate, Fig. 1 (d), which, also, presses the material out of the bucket in the discharge region of the bucket wheel due to its dead weight.

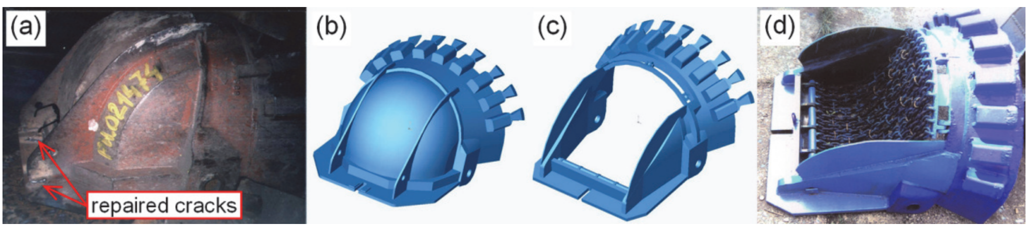

Fig. 1. *Bucket structure: (a) original design; (b) 3D model of original bucket; (c) 3D model of redesigned bucket; (d) reconstructed bucket*

The stress – strain state identification of the original, Fig. 1 (b) and redesigned bucket, Fig. 1 (c), exposed to the forces resisting excavation is done by applying FEM. Results of the original bucket structure’s linear FEA pointed out that, even for a nominal load, calculated stresses exceed the yield stress. Moreover, in some load cases, calculated stresses in the rear side fastening zone are higher than the minimal value of the base plate tensile strength [2]. This fact explains the cracks occurring in the mentioned zone. Due to suitable shaping and better stiffness distribution, stress values in critical zones of the redesigned bucket do not exceed minimal values of the yield stress.

Based on the results of the comparative stress analysis, it is conclusive that the bucket structure redesign perfectly compensates the negative influence of eliminating of bucket back upon its strength, as stated in [1].

After the reconstruction a comparative test of bucket emptying has been done in extremely unfavourable excavating conditions. Before the testing, weights of the original and redesigned bucket were 751 kg and 820 kg, but after the testing, weights were 1280 kg and 960 kg, respectively. Therefore, the weight of adhered material was 529 kg for the original bucket and 140 kg for the redesigned bucket. This fact confirmed the validity of the reconstruction design [1]. The redesigned bucket is currently successfully used on four BWEs of the same type without any failure.

3. STRUCTURAL BUCKET FAILURE

Basically, structural failures of buckets may be divided to minor and major failures depending on level of damage and possibility of repair. Minor failures may be easily overcome by subtle redesign of some elements of bucket structure, while major failures require new design solution which is usually followed by redesign of the bucket wheel body and, accordingly, polongation of downtime of BWE and excavating system as a whole.

3.1 Major structural bucket failure

During coal excavation, major structural failure of BWE SRs 470 buckets appeared. Obviously, Fig. 2, due to level of damage, buckets were totally unserviceable. As a mater a fact, their repair would be completely irrational.

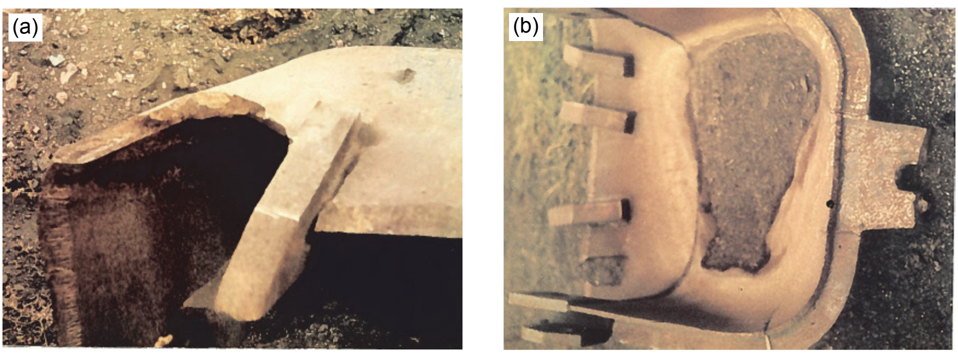

Fig. 2. *Damages of the buckets' structure: (a) damage of the teeth and knife: (b); damage of the buckets' back*

In order to diagnose the cause of the bucket body damages, the following had to be done:

- Calculate the stress state of the bucket body structure;
- Experimental procedure, which, given the nature of the failure, includes: chemical composition and mechanical properties of base metal; impact toughness and hardness; tendency to cracks; working and residual stresses, micro structural examinations [3].

Stress state calculations were done by application of linear finite element analysis. Load cases, used in FEA calculations, were determined according to nominal and limit load of buckets, variation of bucket constrains, variation of teeth exposed to the force resisting excavation, possible values of coefficients of radial and lateral component of force resisting excavation and the direction of the radial component.

Stress values are extremely high, even in the case of nominal load acting upon bucket structure, Fig. 3. By comparing the look-out of the damaged structure, Fig. 2, and the stress fields, Fig. 3, it is conclusive that FEM model truly simulates the bucket structural behaviour under the action of external loads.

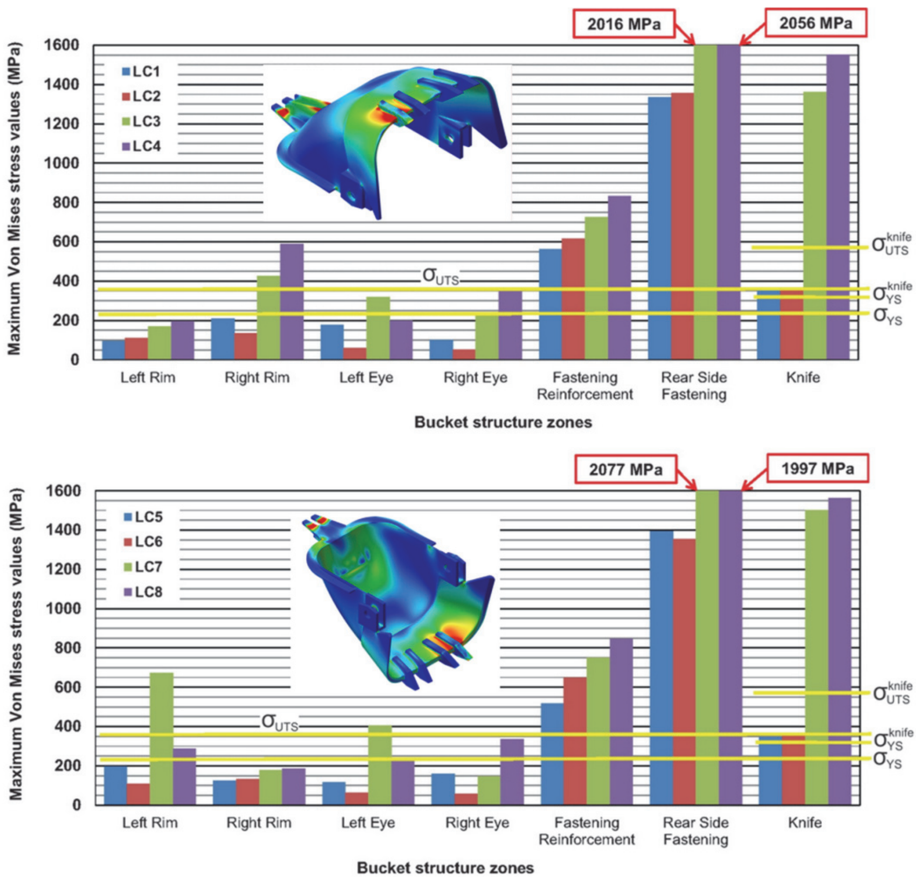

Fig. 3 *Von Misses stresses in case of nominal load (*σ_{YS} = 235 MPa*,* σ_{UTS} = 360 MPa *for bucket body material S235JRG2;* σ_{YS}^{knife} = 325 MPa*,* σ_{UTS}^{knife} = 570 MPa *for knife material S335, according to EN 10025)*

Obtained numerical and experimental results are very important, since they underline initial drawbacks in bucket design and emphasize the importance of subtle load analysis. It is also conclusive that manufacturing process should be done carefully in accordance with prescribed procedures.

3.2 Minor structural bucket failure

BWE SRs 1201.24/4, Fig. 4, was put in exploitation in 2003. During exploitation some drawbacks in buckets' leaning zones such as damages of the pins and bushing of the bucket, damages and plastic deformations of the bucket wheel front supporting eyes, plastic deformations of the bucket wheel rear supporting eyes and bucket "opening" in the rear support zone were observed, Fig. 4 [4].

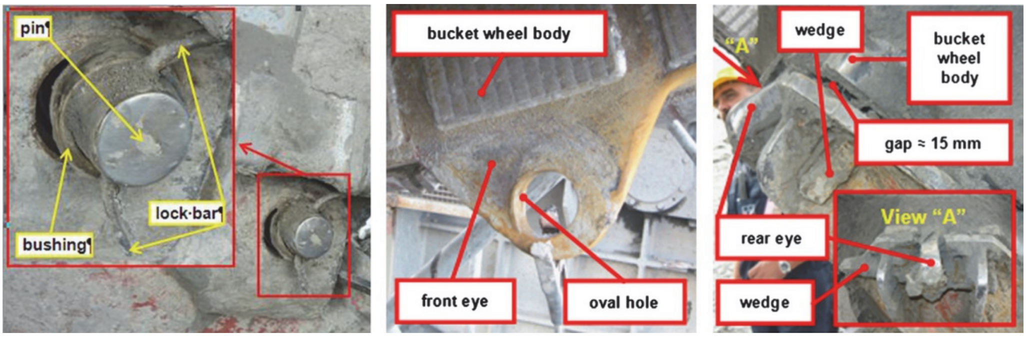

Fig. 4 *Drawbacks in buckets' leaning zones [1,4]*

It was necessary to redesign the bucket supporting zones in order to eliminate the presented damages. After conduction of FE analyses it can be concluded that maximum stress values, which always occur in the zone of the rear bucket support, are for 7-10% less for redesigned than for the original bucket structure. The maximum calculated values of stresses in the original and redesigned bucket structure are larger than the minimum yield stress of steel S355J2G3, Fig. 5.

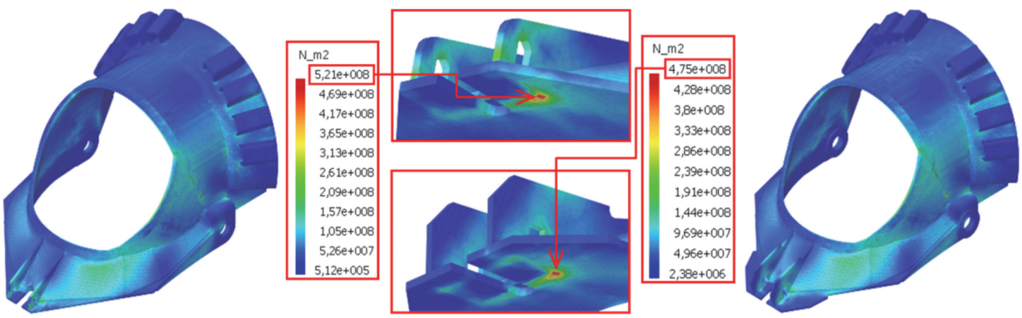

Fig. 5 *Global stress fields (left – original structure; right – redesigned structure)*

This result is a consequence of the assumption that the entire cutting force is implemented in one bucket and only one of its teeth. It is also important to note that natural strain (work) hardening ability of steel, when stress in certain zones reaches values between yield stress and ultimate strength cannot be simulated by application of linear FEA. In real conditions, by redistributing loads in the vicinity zone, the peak values of stresses are relatively fast mitigated and do not exceed the yield stress.

Buckets and bucket wheel were redesigned in October 2009. Validation of the applied solution is done by expert's evaluation of the machine behaviour during exploitation as well as by visual inspection of the critical zones.

4. CONCLUSION

Over the last decades earthmovers, especially BWE have become progressively larger and their mechanisms more efficient. Natural tendency of permanently improving performances of BWE, especially their capacities, has not been adequately followed by calculation methods.

According to type of bucket failure, structural or technological, subtle structure redesign is needed in order to eliminate 'design-in' as well as 'manufacturing-in' defects. The efficiency of the shown reconstructions is based on comparative analysis of the original and the redesigned structure. This analysis enables us to determine weak points in the considered structures and to create a rational redesign, while keeping in mind all restrictions ensuing from installation conditions and functionality. Besides that, results of the mentioned analysis point out advantages of the redesigned structure, especially bearing in mind the already underlined fact that calculation loads are always of a hypothetic nature.

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