



Experimental and numerical inspection of cracks in ferrule cracking of BK1 cement crusher

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ABSTRACT. This article defines the main actions planned in the procedure of non-destructive testing and analysis of defects in the BK1 industrial mill of the cement plant of the GICA group. One of the subjects attracting the attention of researchers and engineers was the propagation of cracks in the shell of the BK1 mill, which behaves like perforated plates. This inspection technique makes it possible to position and size defects (cracks) in the plates. The objective of this work is the detection of cracks in the shell of the BK1 cement mill. In order to avoid bursting of the crusher, the preventive technique of ultrasonic inspection using a multi-element translator is used, while minimizing downtime and increasing production. Found Results allow us to determine and analyze the different types of defects, which will be repaired. It was concluded that the stress concentration at the assembly holes, the vibration effects and gradient of the temperature due to the effect of welding were the causes great residual stresses at the level of the weld. We note the addition of a mass of weld during the repair of the cracks is one causes of the stress concentration.

KEYWORDS. Cement crusher, Ferrule, Non-destructive multi-element control, Crack, Fatigue.



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INTRODUCTION

Production of a cement seems necessary in the economic development of the countries considering the needs, which increase in construction and civil field. If we talk about the BK1 mill from the GICA cement plant (in Algeria), it is intended to grind between 180-250 tons / hour. The presence of the holes in the mill components BK1 are of great importance given their use for assembling the various structures by riveting, by screws or by bolts. However, drilling of mill

components shows damage of a diverse form in some structures that affect mechanical systems life. This phenomenon is then translated, to the macroscopic scale, by the creation of a surface of discontinuity noted as cracks [1,2], which lead to the failure of the construction during their operation due to stress concentrations.

Thus during the operation of the mill, it is exposed to dynamic stresses, which can cause crack formation, this phenomenon due to fatigue can be reduced by controlling and analyzing the various parameters. According to the Wohler curve [3], fatigue resistance can be identified by exposing a large quantity of samples, to variable constraints. The number of cycles is then counted before the sample breaks by setting a limit of 10^8 cycles.

However, in practice, the complexity of the component form and their external condition such as humidity and temperature decrease fatigue resistance. According to Miner [4], stress level can be varied during material operation. High stresses can cause a small crack that can propagate even if the stress level is below the original endurance limit due to the increasing effect of stress. At microscopic scale, presence of defect in material can happens (in homogeneities, inclusions, defects from manufacturing process, etc.) and at macroscopic level, any mechanical part may have holes, section changes or rough surface conditions. Since these conditions favorite the appearance of stress concentrations, it is required to consider the option of crack beginning as well as its propagation during the design of structure. For this reason, designers of structures or any element subjected to cyclic loading must not only take into account the possibility of cracking, but also estimate the rate of crack propagation, to ensure that these cracks do not reach the critical length, which will inevitably lead to failure [5].

The methods of non-destructive testing commonly used are optical procedures, bleeding, radiology, ultrasound, acoustic emission, and eddy currents [6]. Indeed, among the most widespread techniques, the multi-element technique, which are experiencing significant growth in several areas of industrial control [7-15], which consists of scanning the part to be, controlled using transceivers [16], and the method called "Distance Gain Size"(DGS) [17-21]. This technique is used to give information about crack length and depth in structure [22]. The base of conventional ultrasonic testing is transmission, reflection and absorption phenomena of ultrasonic wave propagation in material. The form of wave generated is chosen according to the position of the fault: the surface waves [23] is used for the search for defects located near the surface, the superficial waves [24] for faults located just below the surface, volume waves [8] for faults located at a depth greater than a few wavelengths. The transducer emits an ultrasonic beam through the object at a fixed angle. Transmitted wave train is reflected on the defects and then back to the transducer, which often acts as transmitter and receiver.

The interpretation of the signals makes possible the position and definition of dimension defects or cracks, these have appeared on all the BK1 grinder components (ferrule, input ... etc.). Non-destructive testing depends on the characteristics of the material constituting the part, the intended detection and the nature of measurement [25-26]. It allows optimized management of maintenance [27]. Given the wide scope of non-destructive testing, many methods have been established and studied for examination and detection of defects in various industrial applications [28-31]. This inspection procedure often occurs either during manufacture or during the life of a part and must best satisfy the criteria of reproducibility, reliability, possibility of local or global inspection, sensitivity, speed of execution, cost, resolution, detection, location and identification of defects [32-33].

Our objective is control and analyze lengths, depths of these cracks and their propagation paths. All this, in order to prevent the critical crack length that causes the sudden stop of cement production.

The paper is divided into an experimental description of the installation and process planning and parameters. In the second section, control and inspection procedure is presented with the instrument and technic used. In the last section, we present results of this expertise and the conclusions extracted from this.

EXPERIMENTAL WORK

Installation Presentation

The grinding of cement is ensured by ball mill of beginning of 90 ton / h in closed circuit of 4m diameter and 15 m of length. The mill fan air is purified by an electro-filter. Injection of water into the mill guarantees a favorable purification condition, see Fig. 1.

Material specifications

The structure of installation is making from A42CP Steel material generally used in pressure vessels construction. It is unalloyed structural steels with specified high temperature resistance. Tabs. 1 and 2 provide steel elements composition and mechanical properties respectively according to AFNOR NF EN 10028-2 (06/2003) [34].

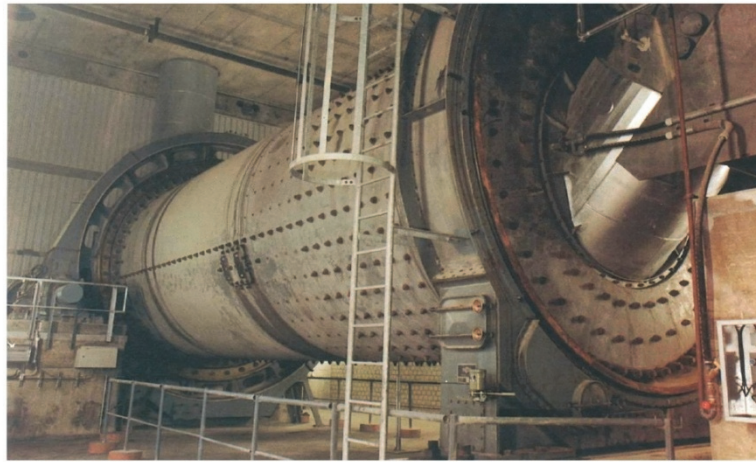


Figure 1: Broyeur Air-Swept [16].

Quality, A42 CP (P265GH) AFNOR NF EN 10028-2 (06/2003).							
C	Mn	S.max	N	Cu	Nb	Ti.max	Fe
≤0.20	0.5-1.40	0.025	≤0.012	≤0.30	≤0.01	0.03	rest
Si	P.max	AL	Cr	Mo	Ni	V	
≤0.40	0.03	≤0.02	≤0.30	≤0.08	≤0.01	≤0.02	

Table 1: Chemical Composition of A42CP Steel Plate.

Quality	Resistance to flow [MPa] ReH	Tensile strength [MPa] Rm	Elongation % (min) A		
P265GH	185-265	390-530	22		
Young's modulus [GPa] E	Poisson's ratio ν	Resilience KV (ISO-V/Charpy-V)			
210	0.3	-20°C 27	0°C 34	+20°C 40	

Table 2: A42CP mechanical properties.

Hardness measurement

Hardness tests show that the material has an average hardness of 152 HB. Note that this given value is within the range of the value given by the supplier equal to 120-155 HB [34] see Tab. 3.

Localizations	1	2	3	4	5	6	average
HB	150.4	151.1	152.7	154.8	153.9	151	152.32

Table 3: Brinell hardness results for much localization.

Developed mapping of ultrasonic control mesh

From Fig. 2 of BK1 grinding mill ring, refining of the shell is done along two axes (horizontal axis represented by units in letters and a vertical axis represented by units in numbers). This description is used for the simple localization of cracks. For periodic inspection of cracks in cement crushers BK1 cement grinders, ultrasonic apparatus brand OLUMPUS model EPOCH 1000i with two translators is used, see Fig. 3. Straight translator of an Olympus brand with a model D 790-SM has a frequency of 5MHz of longitudinal wave type and diameter of 11mm, the second angle translator (multi-element) with a model 4L16-DGS1 has a frequency of 4 MHz of transverse wave type and an angle of 40°-70°, the conducted inspection included the following steps:

- 1) Penetrant testing (cracks on the surface).
- 2) Ultrasonic inspection of internal cracks.
- 3) Ultrasonic inspection of cracks already mentioned on the history of the crusher and repaired "periodic inspection".

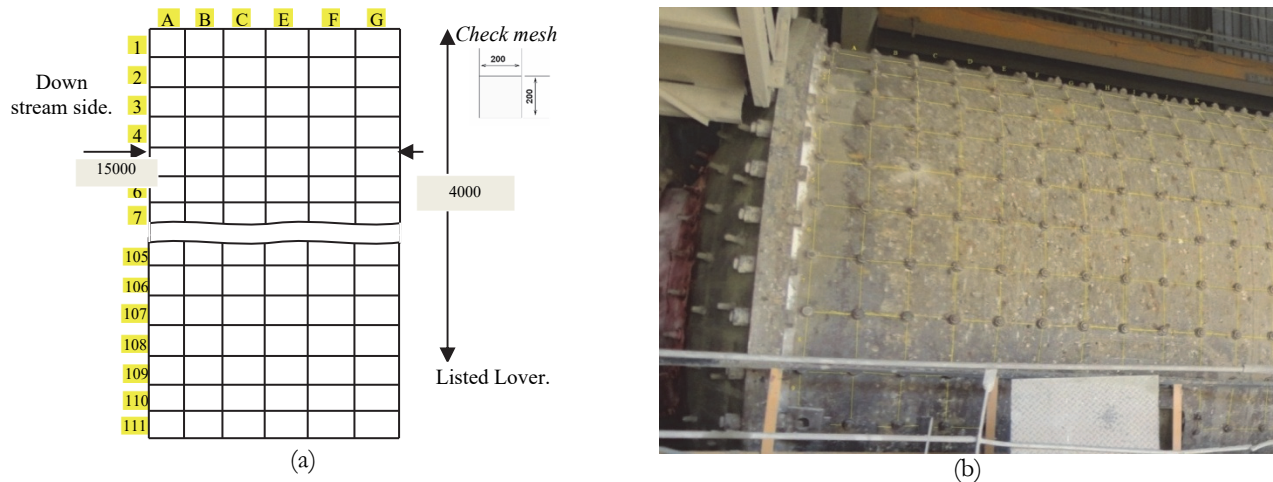


Figure 2: BK1Grinder mesh diagram (a) codified mesh of the ferrule, and (b) real view of the ferrule.



Figure 3: OLYMPUS / EPOCH 1000i.

CONTROL REPORT

Some cracks were triggered from certain locations in the mill grinder shell and propagated to the assembly holes as shown in Fig. 4. For particular cracks, paths propagation was nearly same on both sides of the gear, however there were numerous cases of crack propagation on one side. Given that, the previous appearance of some analogous cracks in some places could be interpreted to faulty design. The measured crack growth rates were compared to those observed over a 4 years age for actual cracks.



Figure 4: Crack that propagates towards the bolt hole.



Crack geometry

According to Fig. 5, we observe a reference of the geometry of the crack near the bolt's holes, or x and the development of the crack in the attack face, and y is the length of the total crack, thus z and the evolution of the crack in width. We note that the red dotted line in Fig. 5 is the history of the crack, the state of the internal crack before it opens outwards (the surface of the ferrule).

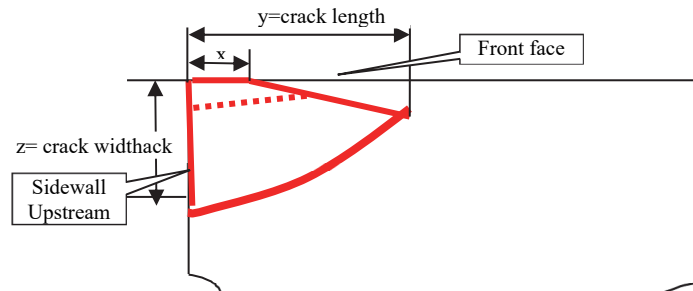


Figure 5: Crack Geometry.

Scheduled conditions of use

Ferrule is subjected to several stresses, which influence its natural life, as well as the appearance of failures. Among the forces applied to the ferrule, crushing force, which is the force under the effect of the balls pressed against the jigs inside the crushing ferrule. The existence in the assembly of many holes that weaken the structure due to concentration of stresses thus the existence of residual stresses due to the plasticity of the zones around the holes, influence of temperature, which deteriorates part material.

For this purpose, the crusher is periodically surveyed by preventive maintenance, in order to ensure proper functioning of the installation. Cracks at the level of the crusher shell require us to control and repair the crack if it takes an optimal length that accelerates at break (see Fig. 6).



Figure 6: Crack repaired (a) far or perspective view of the crack, and (b) near view of the crack

According to the periodical control of the shredder shell BK1, it was observed in the macroscopic plane that the surface of the crack propagates towards the holes, taking into account the concentration of stresses at the level of these holes which generates plastic zones which weaken and favor this propagation of the holes. These cracks have a different length and depth according to the inspection report at the cement plant (see Fig. 7).

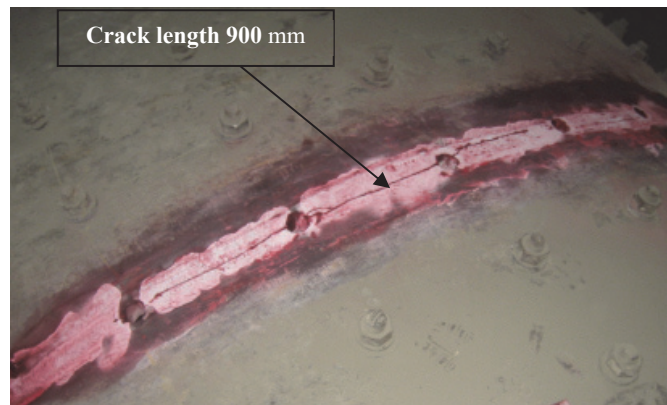


Figure 7: Crack propagates through holes

Crack opening

During the shell inspection period, two cracks were observed, primary the measurement of first crack were 280 mm of length and 56.32 mm in depth (between two bolts), and the second crack with 50mm of length and 33mm of depth, see Fig. 8. The depths of these two cracks were measured with the EPOCH 1000i ultrasonic device, see Fig. 9.

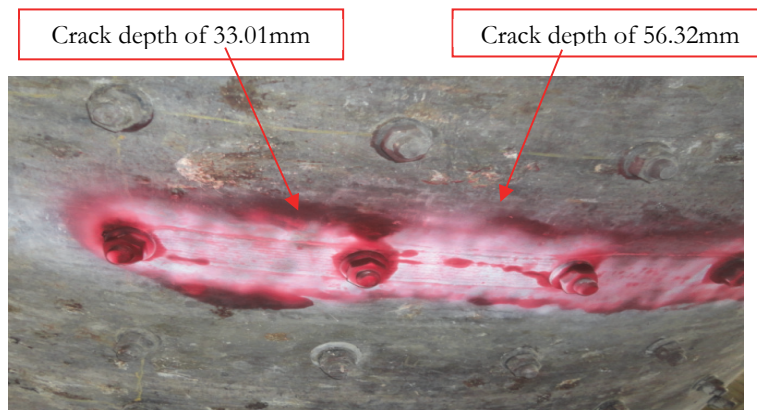


Figure 8: Crack leading to the length of 2400mm

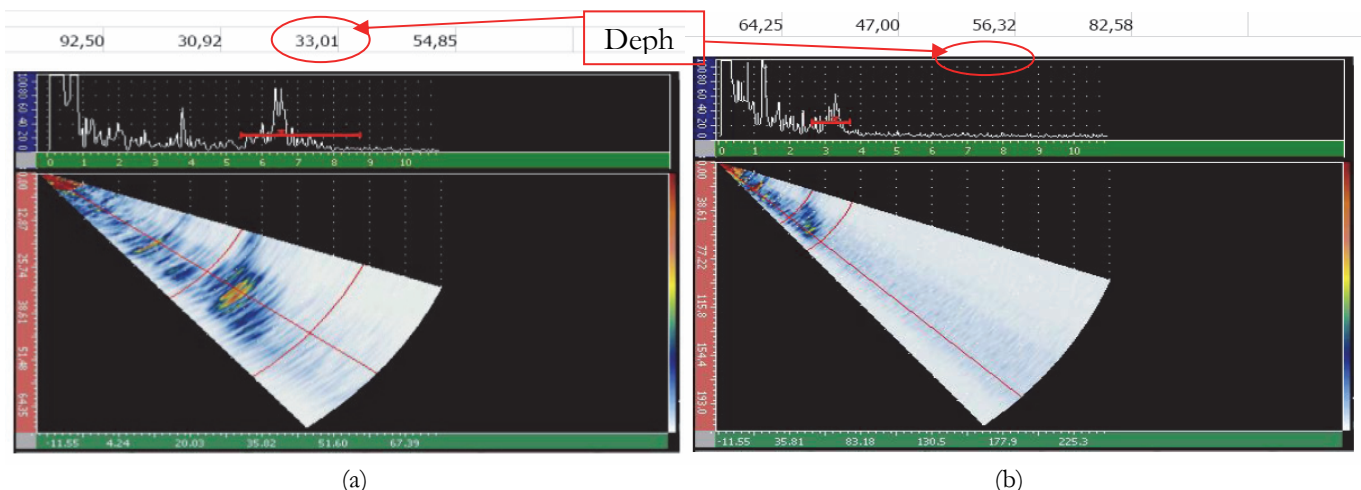


Figure 9: NDC from the depths of the opening crack (a) crack depth is 33.01mm, and (b) crack depth is 50.32mm.

It was observed, that there is proportionality between the crack length and their depth, as well as the tendency of the cracks to propagate towards the holes. We can say that the causes are the concentration of the stresses as well as the presence of residual stresses due to plasticity of the area around the holes.

Crack 1 (F26)

First, we note that a meshing technique was used, to locate the mesh of investigation as for example F26, it is the code of a mesh of the ferrule. This mesh was carried out before starting the inspection of the shell (diametrically in number and longitudinally in letter).

Crack leading to the bolt hole and the free surface of the shell, with different depths see Fig.10.

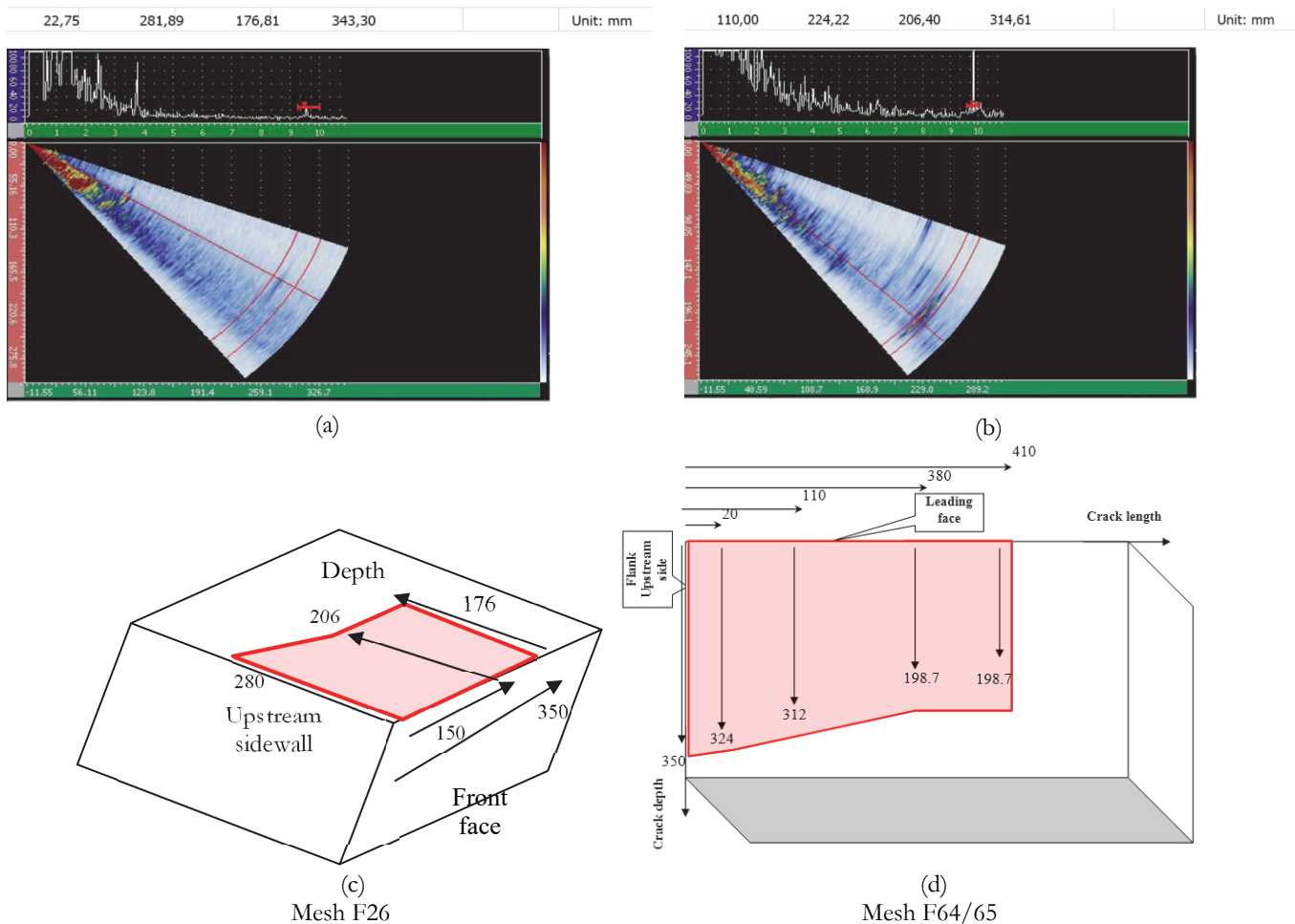


Figure 10: Crack F26-F64/65 leading to the bolt hole and the free surface of the shell (a) Crack depth is 176.81mm, (b) Crack depth is 206.40mm, (c) Crack of the F26 mesh presented in 3D and (d) crack of the F64/65 mesh presented in 3D

Fig. 10a, illustrates the propagation of the crack for the mesh F26 measured (detected) by an ultrasonic measuring device, up to a depth of 176 mm from the ferrule. Then this crack spreads further (more) to a depth of 206mm in the direction of the bolt hole, see Fig. 10b. This situation (configuration) is presented in Fig. 10c, showing the depth of the crack as a function of its position relative to the hole. This observation is even better illustrated by Fig. 10d, which shows the crack of the mesh F64/65 with the depth value of the crack being inversely proportional to the distance from the center of the hole. According to Fig. 10, even though the plane strain condition exists inside the shell membrane, the plane stress condition also exists. The stress gradually increases from zero (crack initiation will cause material relief which generates zero stress) at the surface to its value corresponding to the plane strain inside the shell membrane. Therefore, the plastic zone gradually decreases from its plane stress size at the surface to its plane strain size inside the plate.

Crack development

From Fig. 11 we observe the geometry of the evolution of the crack in 3D.

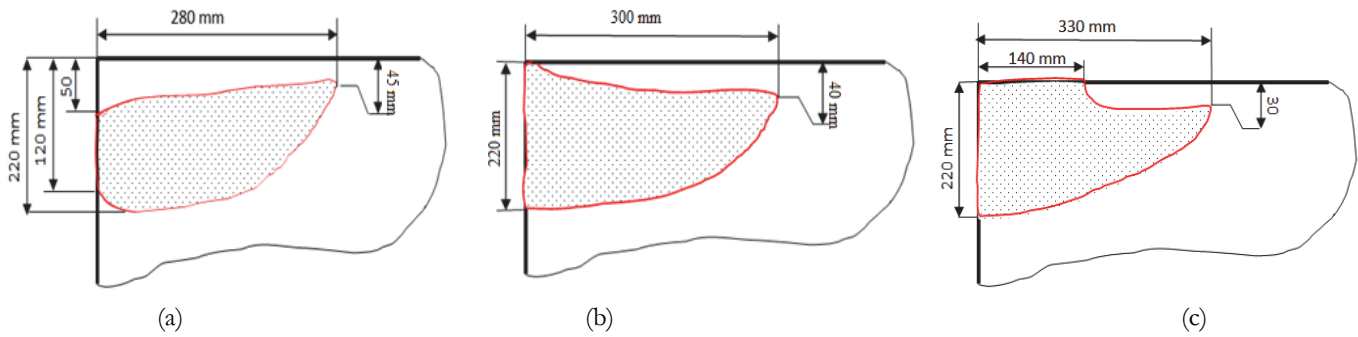


Figure 11: Chronology of crack propagation (a) Internal crack with a depth of 220 mm, (b) Crack which has just opened to the outside, and (c) Propagation of the crack in the external part.

There is an internal crack 280mm long and 220 mm deep (see Fig. 11a). This crack has a distance of the order of 45-50 mm from the outer surface of the shell. It grows towards the surface of the bolt bore (see Fig.11b) as a result of stress concentration in the hole creating a plastic zone. The crack propagates towards the outer surface until it reaches the value of 140 mm (opening crack) (see Fig.11c).

Fragile zone

We noticed that there is a fragile zone near the bolt holes, see Fig. 12.

In Fig. 12a, we observe a display measuring the depth of a crack propagated rapidly after the repair of a crack by welding in the shell near the bolt, see Fig. 12b. This crack initiation caused residual stresses due to structural change caused by melting and the heat effect of welding.

From experience and literature, many elements have an influence on the crack propagation such as plasticity, overload,... etc. Generally, there is a plastic zone near the crack tip, the size of which increases with increasing loading. The presence of residual stresses due to plasticity can have an influence on the toughness of the material, in particular, in the case of a cyclic loading. In some cases, the residual stresses may be higher than the stresses of the external loading; because of the structural change due to the strain hardening effect of the material.

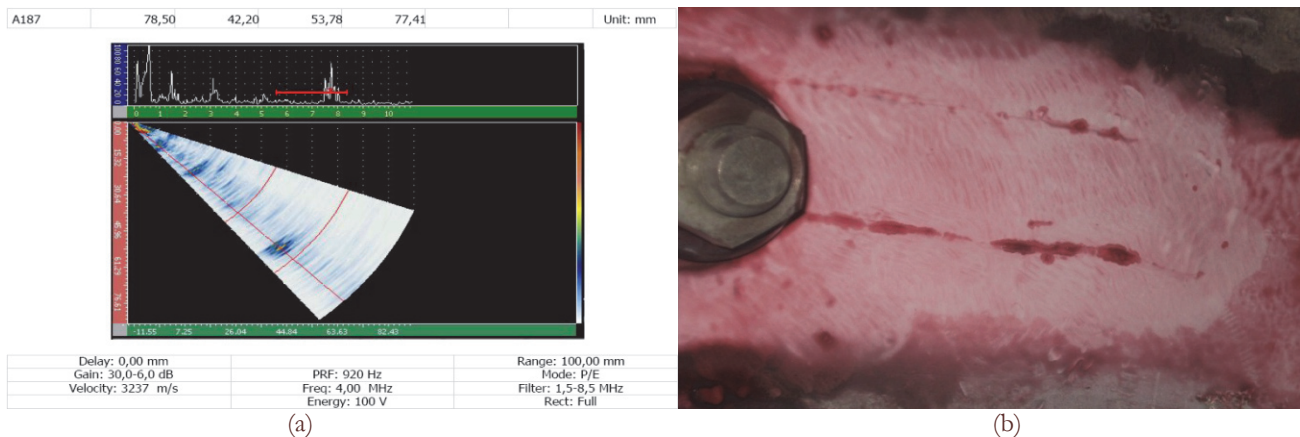


Figure 12: Crack in a brittle welded area (a) crack depth is 53.78mm, (b) brittle area near the bolt.

Evolution of the crack by fatigue

To evaluate the remaining life of the equipment, a failure criterion was required. The most standard failure criterion in fracture mechanics is the appearance of unsteady crack evolution. In this situation, the stress gathered in the dangerous area was caused by deformation of the mill shell, which is in fact a displacement-controlled condition, where growth of cracks can cause stress relaxation. As a result, the remaining life was defined as the time required for the cyclic growth of existing cracks up to ignition and was determined by the use of numerical integration equation of Paris [35]:



$$\frac{da}{dN} = C(\Delta K)^m \tag{1}$$

where:

- ✓ da/dN : The speed of the crack (a is the length of the crack and N is the number of cycles applied).
- ✓ ΔK : amplitude of the stress intensity factor, (MPa.m^{1/2});
- ✓ $C = 3.6 \cdot 10^{-10}$;
- ✓ $m = 3$;

where C and m are characteristic constants of the material [36].

In this study, we used stress and displacement point matching methods for the ease and consistency with our original model. As shown in Fig. 13 and 14, the estimated life obtained from Paris equation and experimental analysis were compared. The analysis made possible better estimation of the actual life of the BK1 mill shell by experimental fatigue analysis higher than that of the analytical Paris methods.

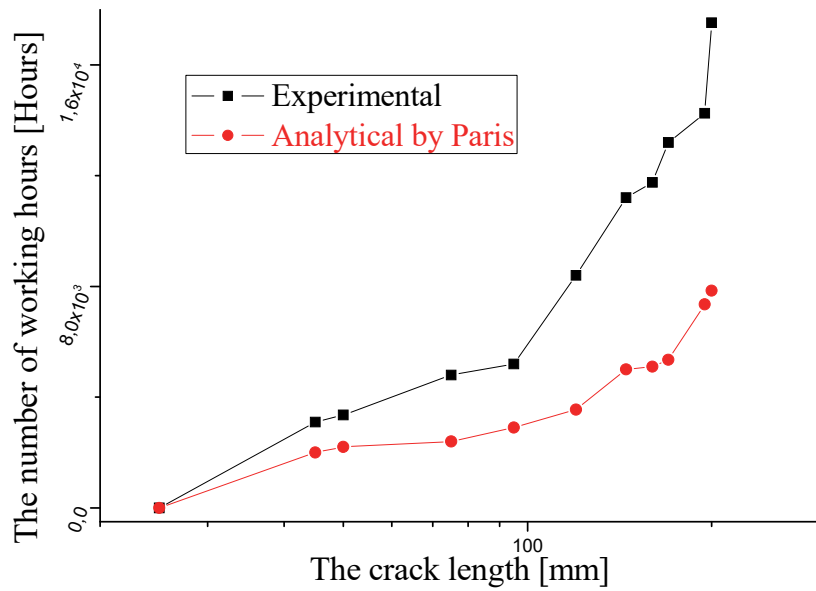


Figure 13: The Crack length measured against the hours of operation of the BK1 crusher.

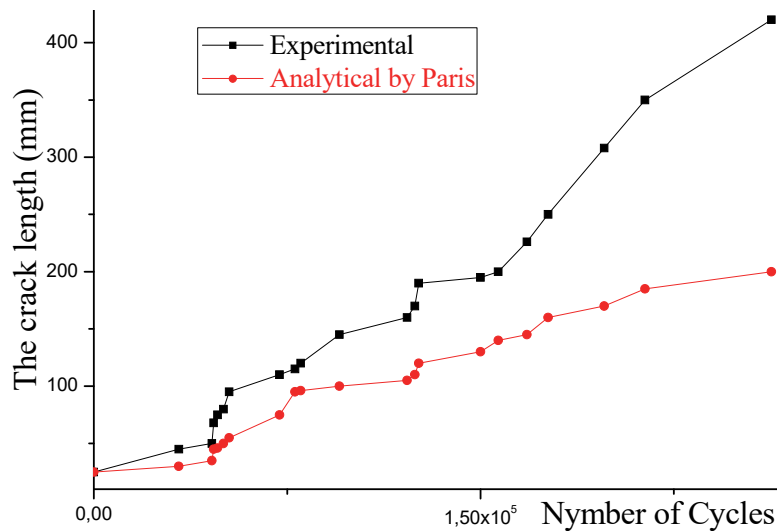


Figure 14: Crack length as a function of the number of cycles of the mill BK1 of the cement plant



The question of the beginning and transmission of fatigue fissures in the BK1 mill shell has been attributed to the presence of reasonably great stress gradients in the critical areas of the assembly holes. These are caused by the deformation of the hull, which is indeed under a condition of controlled displacement, in which the growth of the cracks can lead to a relaxation of the stresses. Therefore, it was observed that under normal effective operational conditions, the growing of cracks would never become unstable and the progress of the cyclic crack would stay until breakdown. We can notice a creation of residual stresses or a decrease in the resistance of the materials. The effect of contact between the shield and the shell through the assembly holes during operation of the crusher, generates stress concentrations, which orient the path of crack propagation towards these holes, and then towards the surface of the ferrule.

Afterwards, the critical cracks were reported to the repair service concerned. Thus, we observed different depths in the opening crack, and part of the figure of the chronology of crack propagation. Finally, the obtained results for the analysis of crack propagation of the hull of the BK1 shredder are acceptable and present good comparisons between the numerical and experimental analysis.

CONCLUSION

One of the subjects attracting the work of researchers and engineers was the propagation of cracks in the shell of the BK1 mill, which behaves like perforated plates. This article defines the main activities planned in the procedure of non-destructive testing and analysis of defects in the BK1 industrial mill of the cement plant of the GICA group. The ultrasonic inspection technique makes it possible to position and size defects (cracks) in the plates. The objective of this work is the detection of cracks in the shell of the BK1 cement mill. In order to avoid bursting of the crusher, the preventive technique of ultrasonic inspection using a multi-element translator is used, while minimizing downtime and increasing production. Found results allow us to determine and analyze the different types of defects, which will be repaired. It has been concluded that ultrasonic phased array control allows us to control and detect the notch of cracks in all positions. Cracks caused by fatigue are almost impossible to avoid completely, however, they can be detected and repaired before they cause sudden shutdown. It is also possible to predict their propagation path, life and schedule outage stops to increase production. As a result, the remaining life was calculated by using the Paris equation. Therefore, after having dealt with the various elements of the investigation carried out, it is essential to analyze the various causes to be related to the incident to detect the essential cause. From the analysis of these factors, the following solutions have been proposed:

- ✓ Perform non-destructive ultrasonic testing.
- ✓ Change the material currently used by the composite.
- ✓ Balance the wear and monitor the vibrations.

The various points should be regularly inspected in small crusher stops;

- Detect and locate the crack (CND)
- Depth and crack length
- Crack after repairing by welding

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