Wear resistance of blades in planetary concrete mixers. Part II: 3D validation of a new mixing blade design and efficiency evaluation

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1. Abstract

This paper presents an improvement of a previous work where the optimization of a two stars' planetary concrete mixer in terms of wear resistance of blades was proposed and a new design of the mixing blades' shape was shown and discussed. Authors propose a new validation of the mixing blades in terms of wear resistance and efficiency, based on 3D optical scanners. A new wear measuring procedure and results are presented and discussed. In addition, experimental tests and results about the efficiency of the new blade in terms of discharge times are shown. The results demonstrate that the proposed new blade's geometry improves the wear resistance, extends the useful-life and enhance the discharge operation.

Keywords:

- 3D wear map
- 3D scanners
- Planetary concrete mixer
- Wear inspection
- Mixing blades

1. Introduction

This paper represents an extension on the paper [1] where an improved geometry of mixing blades for planetary concrete mixers in terms of wear resistance was shown and discussed. In particular, the authors proposed a new blade's design on the basis of a theoretical qualitative approach (fresh concrete model [2–5] actions on the blades [6–9] power consumption [10]), and then they performed experimental campaigns in order to study and demonstrate the efficiency of the new blade's geometry. Experimental results, based on a 2D comparison of worn profiles, showed that the new designed blade was the best one in terms of wear resistance and lower power consumption if compared to the standard T blade normally used in planetary concrete mixers.

The goal of the previous paper was not to quantify the true wear rates of the blades but just to assess which of the new shaped blade was the best in terms of wear resistance and if the new design allowed lower wear rates and longer durability. The goal of this paper is to quantify the volumetric wear rates, to build a 3D wear map showing the true 3D distribution of material losses over the blade's surface and to assess the discharge efficiency.

There are many methods to analyze and evaluate wear and material losses. Açmaz in [11] classifies wear measurement methods into direct and indirect.

In applications where the direct contact with the worn surface is feasible, direct methods are usable and they result to be the best in terms of efficiency, rapidity and accuracy.

The modern measuring technologies are becoming smarter and smarter in many industrial, medical and applied research fields. In the field this paper deals with, the innovative wear measuring techniques can be included in the area of what the authors like to define as "digital tribology". Digital tribology is definable as the totality of the digital techniques applicable in tribology, for wear detection and evaluation [12–15] and for the analysis of contact [16] and lubricating conditions [17].

Among the direct and digital methods to evaluate wear, a very smart technique implies the use of optical non-contact profilometers, 3D scanners and microscopes. The use of those instruments is really recommended as it allows great versatility, reliability and accuracy, as most of the times the use of those instruments does not require the specimen to be dismounted.

Furthermore, excepted the profilometers, they can be the best solution when the specimen has a complex shape. Particularly, the use of 3D optical scanners can give the advantage of being portable, allowing the operator to scan also undercuts in a very simple way. At the same time some of those instruments are also able to generate a full 3D digital model of the specimen in real time and automatically, in order to evaluate the wear 3D distribution by comparison with a non-worn model.

As explained in [1], mixing blades are the concrete mixer's components mostly interested by wear, that is mainly abrasive and erosive. Although their name would suggest the mixing blades are in charge of the mixing procedure, in the studied planetary concrete mixer their main function is the discharge operation and their presence does not significantly influence the homogeneity of the final mixture. Nevertheless, the mixing operation is the most responsible of blades' wear and generates wear mostly on the outer side of the blade. The geometry of this part has not a great influence on most of the mixing procedure but it has a fundamental role during the discharge operation, which is the last phases of the mixing procedure. The mixing blades discharge the concrete from the mixing tank throughout swing-out sector doors, sealed in rubber and hydraulically powered, as shown in Fig. 1. The discharge door opens at the end of the regime phase of the mixing cycle and the mixed material exits the mixing chamber. The discharge door then closes and the next cycle is ready to begin.

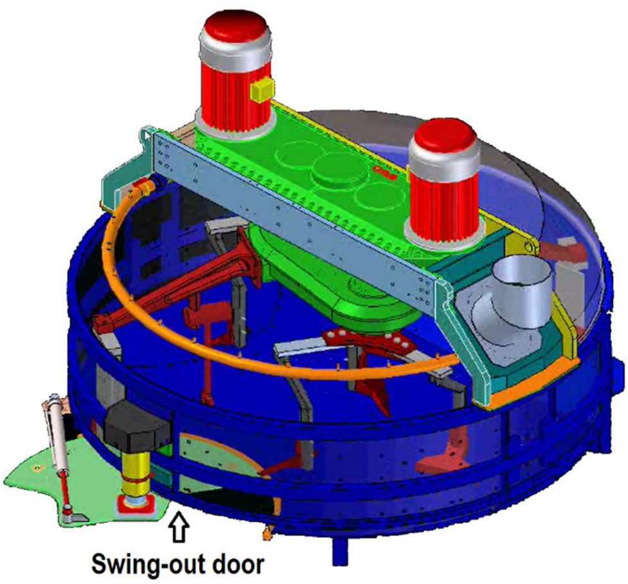

Fig. 1 Discharge swing-out sector door

2. Instruments and 3D wear measuring method

As a consequence of the considerations mentioned in the introduction, in this work a portable optical 3D scanner was used in order to perform wear measurements.

The aim of the research work was to directly measure the worn volumes and the volumetric wear rates of two different mixing blades in order to quantify the better efficiency of the new designed blade with respect to the standard T one, already investigated in [1].

Although in [1] a 2D evaluation was presented by analyzing the whole profile of the blades on the horizontal plane (at a certain distance from the vessel floor), these 2D measurements were not exactly related to the worn volume. Thus, in order to obtain a complete scenario of the material loss, measurements of worn volumes have been performed by means of a 3D metrological instrument.

Since full 3D digital models are directly obtained, the use of this instrument allows a direct comparison of worn volumes, even though the shapes of the two studied blades are totally different over the area interested by wear phenomena.

2.1.Instruments

The metrological device used in this work is Go!SCAN 20 by Creaform (Fig. 2), a latest generation portable non-contact 3D scanner for many industrial applications such as deformation and geometry analysis, quality control, inspection and reverse engineering.

Fig. 2 Go!SCAN 20

This device works according to the principle of active triangulation and the light sources are white LEDs, projecting QR coded patterns on the scene. The scanner is able to reconstruct the full 3D digital model of any target object in real-time and in color, providing a triangle mesh as a result. The real-time reconstruction is performed by using a common reference system, where data from every scanned frame are merged into a complete model. This process is called dynamic referencing registration and is based on three different types of self-positioning references: physical targets, virtual targets and geometries.

Physical targets are light adhesive circles made of reflective materials with or without black contours for an easy detection by the optical device. In the case represented in Fig. 3 physical targets are white with black contour. Physical targets are attached before scanning to the specimen or on the scene and they allow to register all the different camera frames. If the targets are attached to the specimen, then it can be freely moved in the space keeping the references joined with the scanning system. Vice-versa the specimen must be kept in the initial position during the scanning procedure. The set of targets constitutes the global positioning model and as the scanner is moved around the part, new targets are detected and registered on it. Physical targets are used when geometrical characteristics of the object are repetitive and similar frame by frame. The targets positioning method is the only one that enables portable 3D scanners to deliver metrology-grade results, which in the past were restricted to contact CMM machines stationary optical 3D scanners.

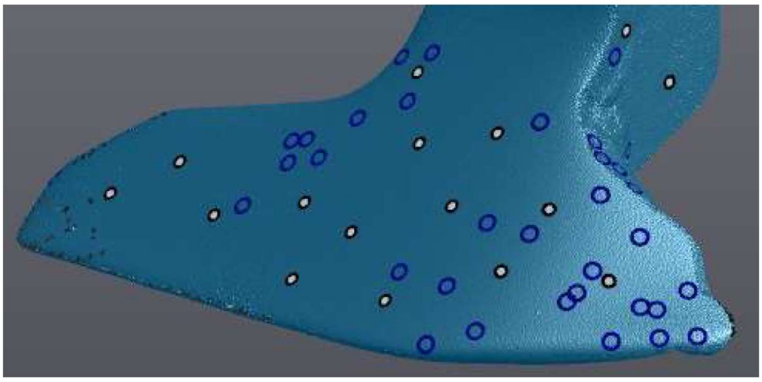

Fig. 3 Positioning references

Virtual targets are represented by blue circles in Fig. 3. They are provided by texture attributes of the target surfaces, when the natural features of the scan object are prominent enough to be detected. At each new frame, detected virtual targets are compared with previously registered ones to match up the images and help determine the object's position.

The positioning method based of geometries works by comparing each frame with the previous one by best fit algorithms.

Table 1 reports the main specs and performance parameters of the scanner used in this work.

Table 1 – Go!SCAN 20 specs and performance parameters

Specs	**Go!SCAN 20**
Measurement rate	550000 measures /s
Scanning area	143 x 108 mm
Light source	White light (LED)
Resolution	Up to 0.100 mm
Accuracy	Up to 0.100 mm
Volumetric accuracy	0.300 mm/m
Positioning methods	Geometry and/or color and/or targets
Stand-off distance	380 mm
Depth-of-field	100 mm
Part size range	0.05 – 0.5 m
Texture resolution	50 to 250 DPI

2.2.Experimental tests: setup preparation and 3D scanning

The 3D validation of the new blade design in terms of better wear resistance has been performed by measuring the worn volumes and the volumetric wear rates of a standard T blade and of a new shaped blade and performing a detailed direct comparison. To do this, the 3D scanner was used to create the digitized 3D models of the worn T blade and of the worn new shaped blade.
The two blades under study (Fig. 4) have been chosen among the ones coming out at the end of the second test campaign described in, where three T blades and three new shaped blades were assembled in a two stars planetary concrete mixer and worked for a certain time, up to wear, assuring the same working time and the same service conditions with the same mixture composition. The specific choice of which blade to measure among the tested ones is not crucial as in [1] we observed that the results corresponding to equal blades after the experimental campaign were similar.

Fig. 3 Worn mixing blades under study: (a) T blade, (b) new designed blade

After dismounting the blades from the test mixer and before scanning, they were cleaned in order to remove the concrete at least around the worn zone. Then physical targets were applied on the entire surface of the blades in order to guarantee that also the flat surfaces could be easily measured. Moreover, virtual targets provided by the blades′ natural texture were detected. Thus, in this case a hybrid self-positioning method was used, by combining physical and virtual target modes together with geometric positioning (Fig. 5). The calibration procedure of the scanner was launched and performed before scanning, in order to assure the achievement of the performance reported in Table 1.

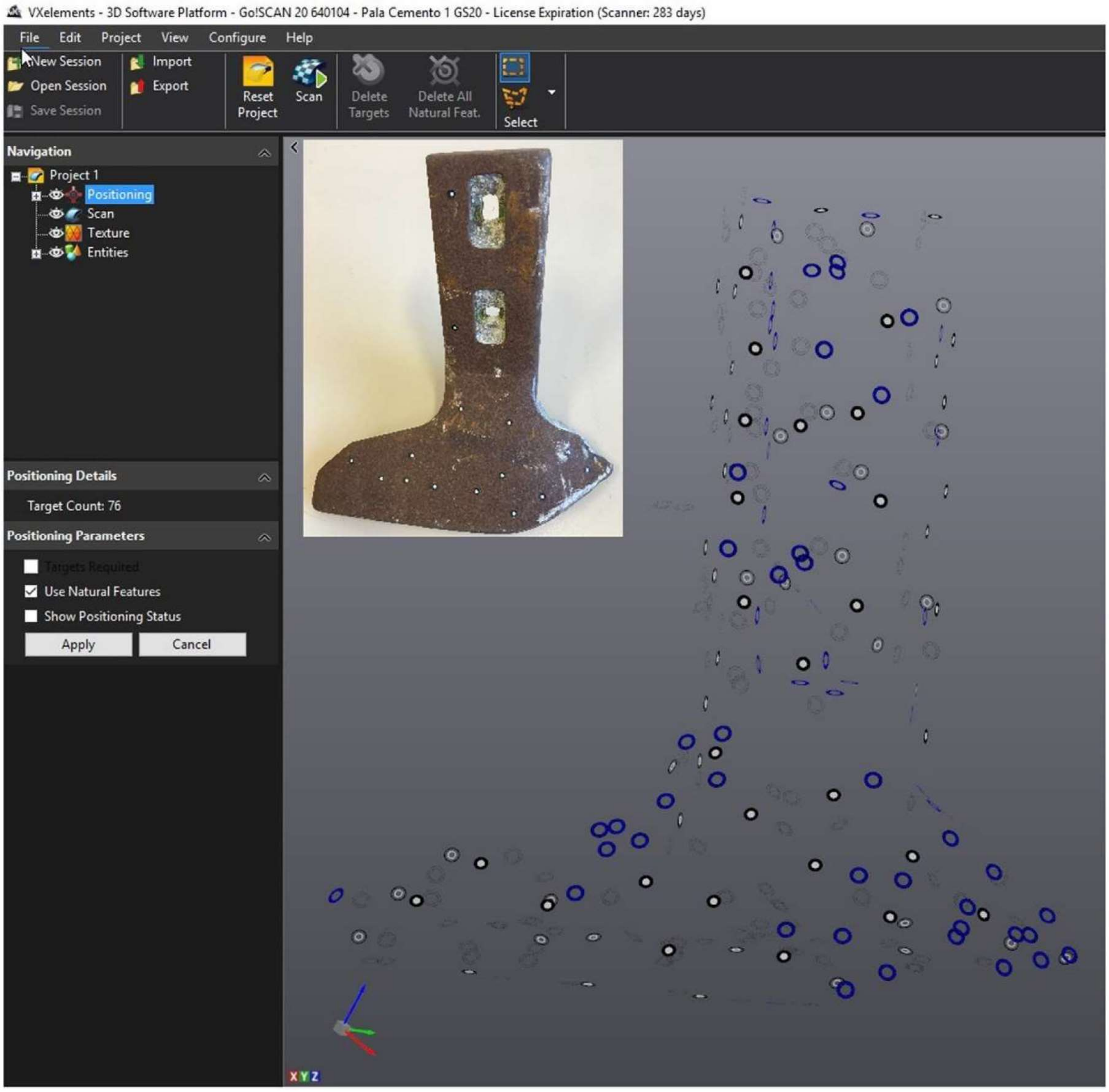

Fig. 4 Hybrid positioning model for the new blade

The software used for the acquisition is VXelements 4.1 SR2.

The scanning procedure was performed at 0.2 mm resolution, and the result is represented in Fig. 6. As the figure shows, even if the scanner is able to create watertight models, the full 3D model resulting from the scanning was not watertight, in fact it contains some holes, but all the holes are located in areas not interested by wear. This was done in order to get a mesh with an acceptable number of triangles (6.674.731, in the case of the new bade) to be easily and rapidly calculated by the software and avoiding to lose data in the areas of interest. As it can be seen from Fig. 6, the results of the scanning procedure are rough, as no automatic mesh optimization tool was enabled (mesh and boundaries optimization, decimation, hole filling). Just an automatic isolated patches removing tool was activated in order to remove the data deriving from the scene around the blade under scanning.

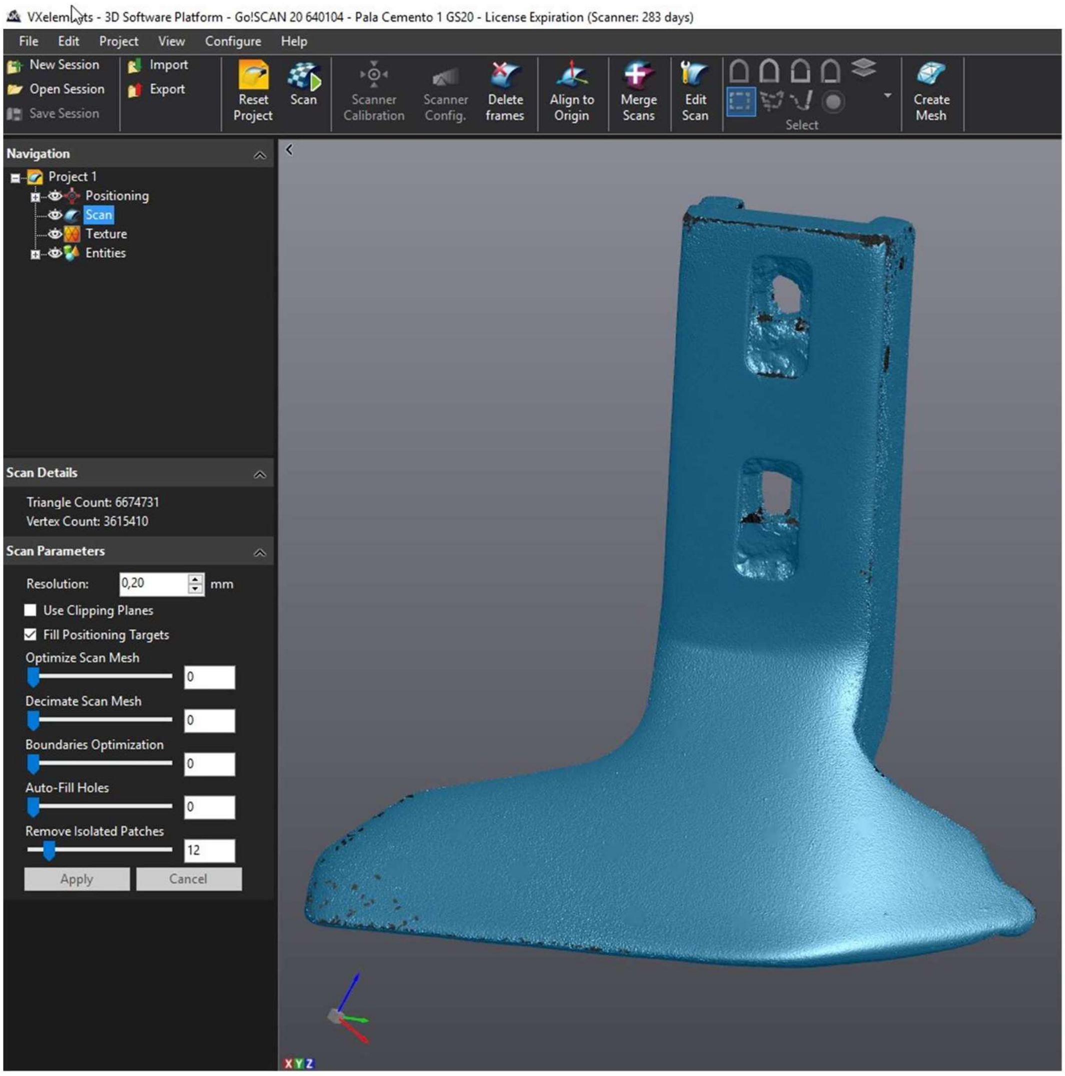

Fig. 5 Scanning parameters and results

2.3. 3D data optimization

Before performing the wear inspection, the output data from the scanning procedure were optimized in terms of mesh quality, in order to present high quality results. This mesh optimization procedure was performed taking care of preserving the original shape and volume of the rough 3D data, through specific and known algorithms, in order to allow metrological evaluations. The software used for the data optimization process was VXelements 4.1 SR2. The steps for the optimization include the detection and restoration of errors as non-manifold edges, self-intersections, highly creased edges, spikes, small components and small holes. The result of this process is shown in Fig. 7.

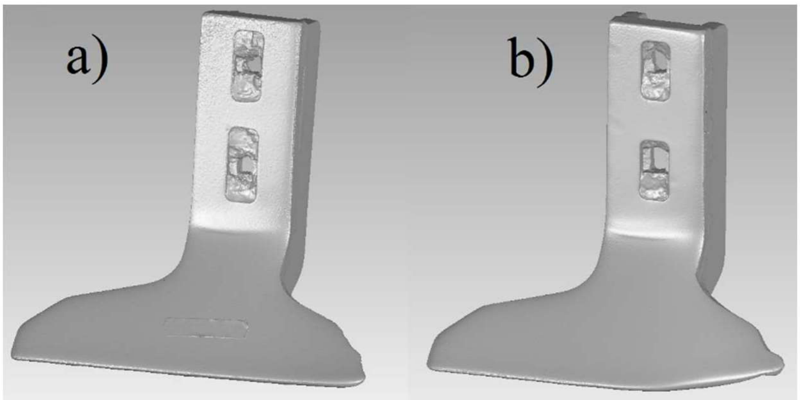

Fig. 6 Optimized worn blades' 3D models: a) T blade, b) new blade

2.4.Wear inspection and results

After the mesh optimization process the worn blades' 3D models were compared with the corresponding reference nominal 3D CAD models, shown in Fig. 8, through a digital inspection procedure. The software used for the inspection process was Geomagic Studio 2014.2.0.

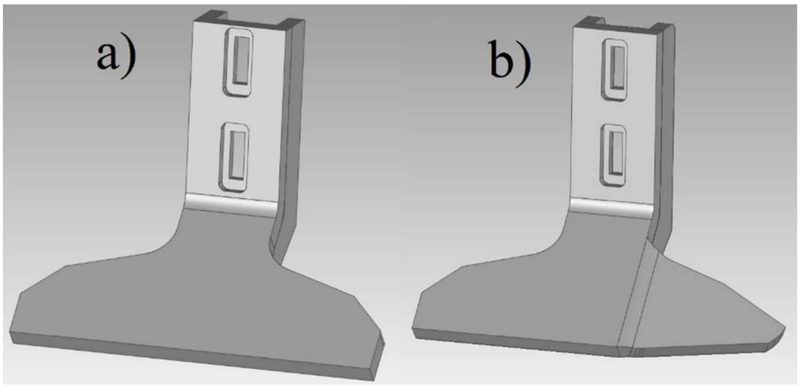

Fig. 7 Reference nominal 3D CAD models: a) T blade, b) new blade

As the physical blades fit with CAD model and as the tolerances of the production process are negligible with respect to the order of magnitude of the wear, the CAD models can be considered efficient for the comparison.

The digital inspection procedure was performed by:

1) Aligning and superimposing the worn and the CAD models of standard and new blades, in order to evaluate the deviations;
2) Calculating the difference of volume between the worn and non-worn models, in order to evaluate the wear rates.

3) Building the 3D color map of deviations considering the outer half blade, as it is the part mainly interested by wear. As Fig. 7 shows, this part corresponds to the right side of the blade.

Regarding step number 1, the alignment and fine registration can be performed basically by two criteria: the best-fit alignment that work by registration algorithms minimizing a distance criterion and the alignment based on reference entities as planes, lines, points.

Since the alignment procedures can be an error source the choice of the surface portions to use as reference for the alignment is crucial. In this case the alignment was performed by both the procedures and particularly by a pre-alignment based on corresponding points on the two models, followed by a fine best-fit. The points for the pre-alignment procedure were chosen on the unworn surfaces in order to get a correct registration.

Regarding the step number 2, the wear rate was calculated according to the following equation:

$$\chi = \frac{V_i - V_f}{V_i} \% \qquad (1)$$

where V_i is the volume measured in the reference model and V_f is the volume measured in the 3D model of the worn component.

The results showed that the wear rate of the new blade is the 3% lower than the wear rate of the T blade and thus the new blade allows longer durability than the standard one.

Fig. 9 shows the result of the 3D wear maps construction. The color maps represent the distribution of deviations between the CAD reference model and the 3D model of the worn blade in mm, taking the CAD models as a reference. The red color corresponds to the material loss and the blue color corresponds to the deposit of material on the blade. In fact, some concrete has remained on the portion of blade not affected by wear. Those pictures highlight that the worn T blade has a greater deviation from the reference model than the new blade. Moreover, it can be observed that the T blade is affected by wear upon a bigger region than the new one.

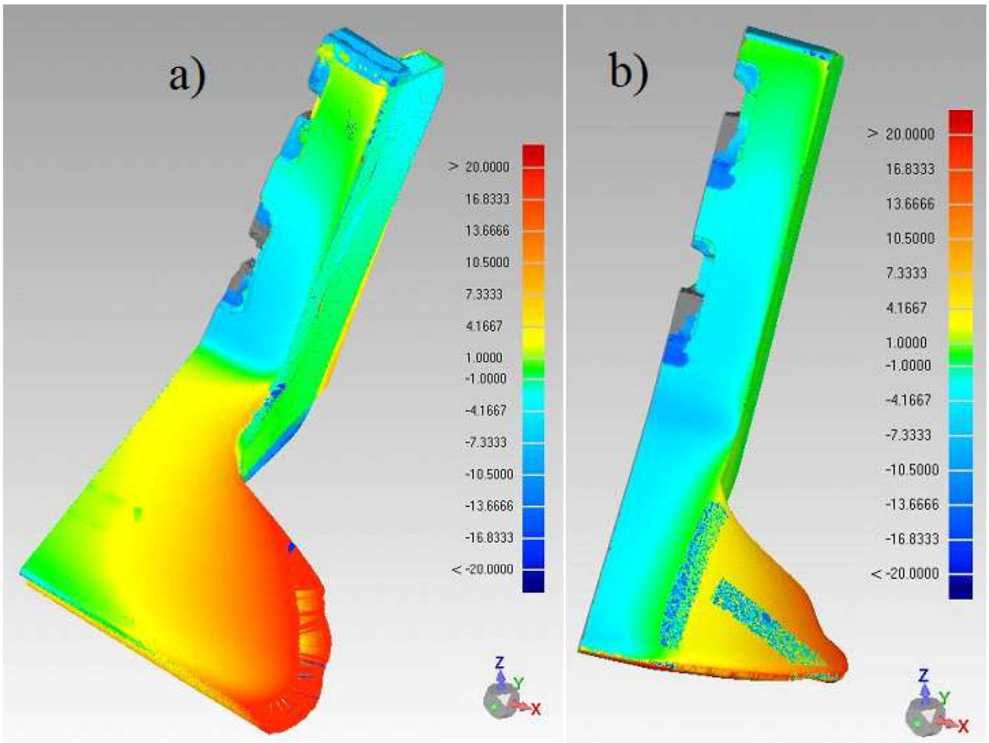

Fig. 8 3D wear distributions in mm: a) on the standard blade, b) on the new blade

3. Tests about the discharge efficiency and results

The concrete is discharged from the mixer's tank thanks to the combination of the swing out door's opening on the tank's bottom and of the mixing blades' discharge action. Thus, the evaluation of the discharge times was carried out in order to study the discharge efficiency of the new shape.

For this purpose, an experimental campaign was performed by mounting six standard T blades and six new blades in two identical planetary concrete mixers (mixer A and mixer B in Fig. 10) with two stars and by measuring discharge times. Measurements were performed 10 times on ten cycles in condition of concrete mixer's full load and wear progress.

All the results and the average discharge times are reported in Table 2.

As it can be observed, the discharge time referred to the new blade design is reduced, if compared to the T blade's one. This reduction is estimated to be equal to the 8.3% so that the new blade design is also able to accelerate the discharge operation. Besides, Table 2 shows that the new blade keeps better discharge times than the T blade also during the wear progress, thanks to the fold.

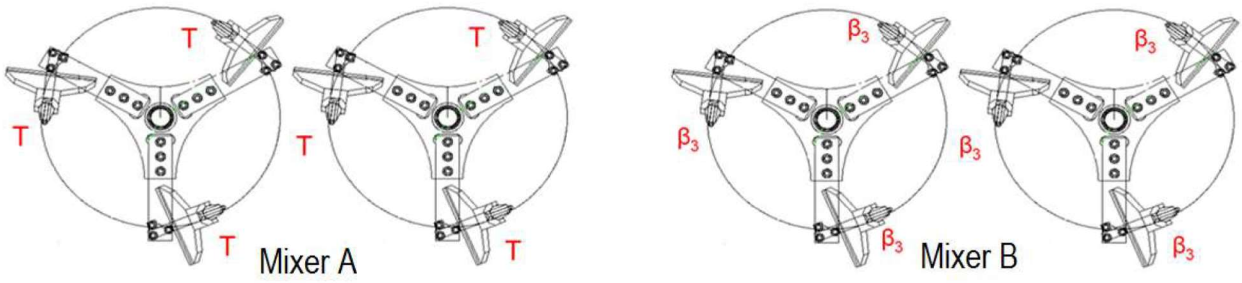

Fig. 9 Experimental setup for the comparison of discharge times

Table 2 – Discharge times for different blade's shapes

Test no.	**Mixed concrete volume (m^3)**	**Mixer A (s)**	**Mixer B (s)**
1	1.5	35	33
2	1.5	36	34
3	1.5	36	33
4	1.5	35	33
5	1.5	36	34
6	1.5	36	33
7	1.5	36	33
8	1.5	37	34
9	1.5	38	33
10	1.5	37	33
Mean Value	1.5	**36.2**	**33.2**

4. Conclusions

2D evaluations presented in [1], were not exactly related to the worn volume and, as expected, they gave different quantitative results, because just the 2D profile of the blades on the horizontal plane (at a certain distance from the vessel floor) was measured. This was just a first result, encouraging the conclusion that the new design was better in terms of wear resistance. The use of 3D metrological instrument to assess the true better efficiency and get a complete scenario of the material loss.

From the results obtained in this research work it can be observed that the new shape design allows longer useful-life with respect to the standard T design, as the wear rate resulted to be the 3% lower. Regarding the discharge operation, that is the main function of the mixing blades, the results showed that the new design is also able to enhance the discharge times, making the discharge operation faster and more efficient. The design of the new blade was patented [18].

The final configuration of the new blade consists in the same designed shape, realized in steel and covered with welded stellite (Fig. 11). This is a further improvement to enhance the wear resistance.

Fig. 10 New blade's final configuration

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