Friction and wear characterization of a new ecological composite: glass waste beads reinforced epoxy

Alessandro Ruggiero, Vincenzo D’Agostino, Massimiliano Merola, Petr Valasek, and Karolina Dedicova

***Abstract* –** Sandblasting is a process that allows smoothing and cleaning rough surfaces, by means of a hard abrasive material streamed at high pressure against the interested surface. The abrasive material could be glass beads, which are wasted after the process. This paper investigated the opportunity to recycle the glass beads as reinforcement inside a polymeric matrix. This new composite material could be an economic and green alternative to the more common polymer matrix composite (PMC). Therefore, the tribological properties of this composite were studied through reciprocating sliding tribotest. The influence on friction and wear of different glass dimensions and concentrations within epoxy resin were analyzed.

***Keywords* –** Composite, epoxy, glass, tribology, waste.

I. INTRODUCTION

Mutual interaction of hard inorganic particles or fibers with polymeric, metal and ceramic materials creates entirely new systems – composite materials that exhibit specific mechanical characteristics [1]–[4]. Composite and multi-phase materials leaded to improved component with higher specific properties and better surface characteristics [5]–[7]. Among the material properties, which are conventionally enhanced with the presence of hard inorganic microparticles, there is also wear resistance [8], [9]. Satapathy and Bijwe [8] have used SiC and Al_2O_3 particles (40–175 μm) to increase the wear resistance of phenol-formaldehyde resins. Similar results are described in numerous papers [9]–[13]. In the field of bio-tribology, the need of improving the life time of prostheses, pushed forward the realization of ceramic and polymer composite, with enhanced wear resistance in dry and lubricated conditions [14]–[17]. In many works is described the interaction of particles based on glass and resin – e.g. to reduce the cost while maintaining good adhesive characteristics of the system while increasing wear resistance [10]. Epoxy and other reactive resin may also be carriers of material recycling. Particulate fillers based on waste can be added into these resins. In addition to changes in mechanical properties (increase of wear resistance for hard inorganic particles) the final price of the material is reduced by this kind of material recycling [11], [12].

Glass beads are hard abrasive materials, which are used for blasting materials [18]. This abrasive material is not usually used after blasting and therefore is eliminated – landfilled. The glass powder production technology uses sorted glass cullets of mainly packing glass, which is not contaminated and it does not influence the required quality of arising product. The glass powder is therefore suitable for filling the polymeric materials.

This paper describes the possible utilization of material of this kind of waste in the form of a particulate composite. Mechanical properties – especially hardness of glass beads and glass powder – predetermine the resulting composite materials for applications that require wear resistance. For this reason, the aim is to define the contribution of the wear resistance of such systems.

II. MATERIALS AND METHODS

Matrix of composite systems consisted of two-component epoxy resin Glue Epox Rapid. The filler was waste from the blasting (glass beads) and glass powder. The particle size of glass beads, determined at a stereoscopic microscope, matched the dimensions associated with the following specimen nomenclature: B112: 187±46 μm, B134: 139±39 μm, B159: 86±16 μm. The glass powder is produced by the company Refaglass s.c. (Czech Republic), the particle size of glass powder corresponded to 48±24 μm, and the relative sample were named POW.

Test specimens were cast into moulds of two component rubber (Lukopren N). Prior to casting the mixture of resin and fillers was mechanically stirred in an ultrasonic bath – minimization of porosity. Test specimens were prepared with variable volume fraction (percent) of the filler.

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For the investigation here described, the bulk resin and three different glass concentration within the resin were tested: 5, 20 and 35 %.

Friction and wear tests were conducted using a ball-on-flat apparatus (Fig. 1) on a Reciprocatory Friction Monitor (Ducom Instruments, Bangalore, India). The tribometer allows analyzing the tribological behavior of tribopairs with non-constant relative speed [19]. In this study the tribopair was made up by a titanium ball rubbing against a flat specimen of the composite materials. The ball was a 6 mm diameter $TiAl_6V_4$, the specimens were cut with dimensions of 25 mm × 25 mm × 5 mm. The reciprocating movement is imposed to the sphere holder by a stepper motor, which swing a portion of the complete round back and forth. The spinning motion is therefore converted to a linear movement by a rocker arm. The friction force is constantly evaluated through a load cell, therefore the coefficient of friction evolution is recorded throughout the test.

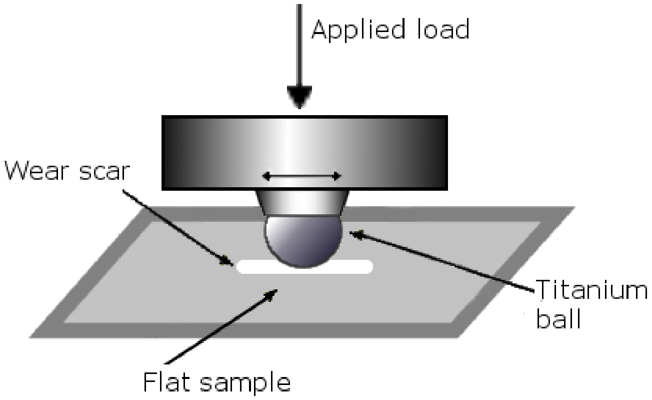

Figure 1: A schematic representation of the reciprocating tribo-apparatus.

To evaluate the wear, in term of mass loss, a gravimetric analysis was executed. Before each test the specimen and the ball were cleaned, using ethanol and compressed air, then weighted on a precision scale (Gibertini, Milano, Italy), with a resolution of 0.01 mg. When the test terminated the sample and the sphere were cleaned and weighted again. The procedure is partially in compliance with the provision of G133 (ASTM standard), Procedure A (for dry contact), because the normal force – due to instrument limits – was 20 N, instead of 25 N. The test duration was 50 min and 6 s, instead of the 16 min 40 s prescribed by the standard, the longer time was necessary to obtain a sizable wear. Using 5 Hz of oscillation frequency and 10 mm of stroke yielded the ball to slide for a total distance of 300.6 m. Every test was realized in room temperature, in laboratory air at controlled levels of relative humidity.

Furthermore, a 3D topography analysis was carried out on the PLu Neox (Sensofar, Terrassa, Spain). The topography yields the characterization of surfaces, estimating parameters such as roundness and roughness, useful for the understanding of the wear intensity and processes [20]. The worn surfaces were cleaned from debris with ethanol and compressed air and scanned under a confocal lens of 5× and 20× magnification, for specimens and spheres respectively. The sensor head – carrying the lens – moved along the Z-axes (orthogonal to the surface plane), with different step sizes, depending on the magnification lens.

III. RESULTS AND DISCUSSION

The theoretical density of the composite mixture corresponds to 1.22 – 1.62 g cm^{-3} (the density of resin 1.15 g cm^{-3}, the density of glass beads and powder 2.5 g cm^{-3}. When calculating the theoretical density, air pores are not considered, the perfect wettability of the filler by the resin is considered as well as the uniform distribution of microparticles in the resin. The lowest average porosity 4.2 % was detected on the tested samples with 10 % glass powder in the resin, the highest average porosity corresponded to 7.9 % (glass beads B112 30 %).

In Fig. 2 is illustrated the evolution of the coefficient of friction (μ) for the specimens analyzed. These graphs are relative to a single test per tribopair, to have a better understanding of the image. The evolution of the bulk resin, coupled with Titanium ball – for now on omitted for simplicity –, presents the highest level of μ, each plot contains a comparison with this evolution. Its characteristic clearly underline the main effect of the reinforcement: a reduction of the friction coefficient.

Regarding the different glass concentration investigated, a common observation can be made: their evolution is characterized by a changeable phase in the beginning of the test. The main explanation to this issue is the glass dispersion inside the matrix. The epoxy resin is firstly the only part in contact with the counterbody, afterwards the wear of this substrate uncover glass particles. These beads are exposed and

Table I : Summary of the tests results

	Bulk Epoxy	POW			B159			B134			B112		
Glass vol. fract.	0 %	5 %	20 %	35 %	5 %	20 %	35 %	5 %	20 %	35 %	5 %	20 %	35 %
Friction Coeff (-)	0.67 ± 0.029	0.70 ± 0.008	0.65 ± 0.009	0.65 ± 0.004	0.44 ± 0.005	0.50 ± 0.019	0.48 ± 0.009	0.48 ± 0.007	0.45 ± 0.01	0.45 ± 0.004	0.42 ± 0.003	0.40 ± 0.004	0.39 ± 0.014
Specimen wear (mg)	0.00	0.82	1.18	0.39	2.04	0.12	0.16	0.06	0.09	0.21	0.07	0.05	0.49
Ball wear (mg)	0.00	0.35	0.32	0.15	1.64	0.84	0.16	0.36	0.14	0.21	0.10	0.10	0.68
Ball wear diameter (mm)	0.00	2.05	1.83	1.52	1.42	1.14	1.93	1.64	1.43	1.44	2.36	1.97	1.52

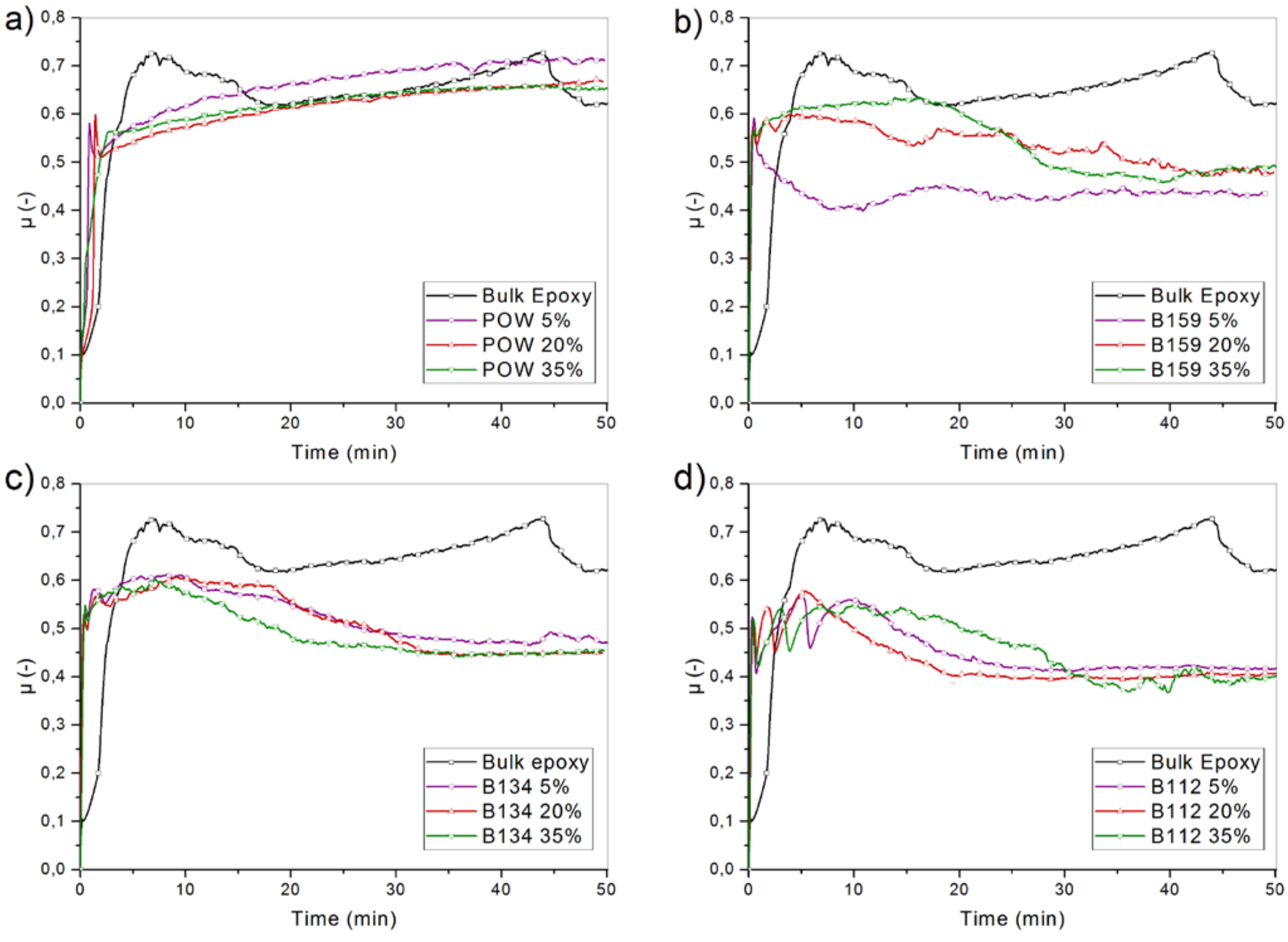

Figure 2: Evolution of the friction coefficient. Comparison of the bulk resin results and the reinforced specimens: a) powder, b) B159 beads, c) B134 beads, d) B112 beads.

become part of the tribological system, thus they act as a third body and contribute to the load carriage. These combined actions resulted in a μ oscillation followed by a stabilized value, which is generally lower than the one obtained with the bulk resin. The exception is represented by the powder reinforcement, in which case the μ has a gait similar to the bulk resin: a slightly increasing trend. In the B159, B134 and B112 samples, the stable evolution is reached usually after 30 minutes. Therefore, the mean value of the μ was evaluated by averaging the values in the last 20 min 6 s. Statistical analysis on these values brought to the box-plot representation of Fig. 3. The main remark obtainable from this graph is a reduction of μ as the glass particle dimension increases. This statement is also described in Table I, where the mean values and the standard deviation are summarized. Regarding the glass concentration, for a fixed particle size, the mean values do not always exhibit a specific trend. In the case of B159 samples, the lowest μ value of the three cases is the one relative to the less reinforced specimen, i.e. 5 % of glass volume concentration. In the other samples the less reinforced specimen is always the one with the highest values of the friction coefficient, the other two glass concentration (20 % and 35 %) usually gives values close to each other.

The tribotest instrument recorded also the evolution of the frictional force during the sliding of the sphere along the test duration. This recorded data could provide information on the gait of the force and on the transition between the static and the kinetic phases. During the inversion of the harmonic motion, the ball is temporary still, this lead to a peak of the

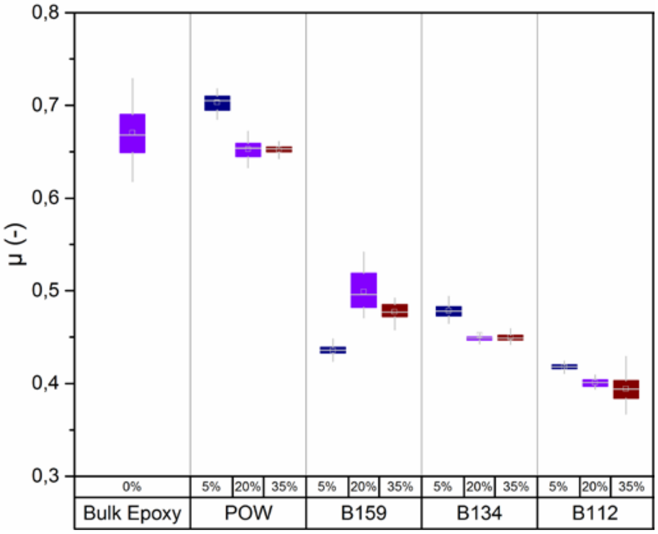

Figure 3: Statistical evaluation of the friction coefficient during the last 20 minutes of the test. Comparison across the different filler dimensions and concentrations.

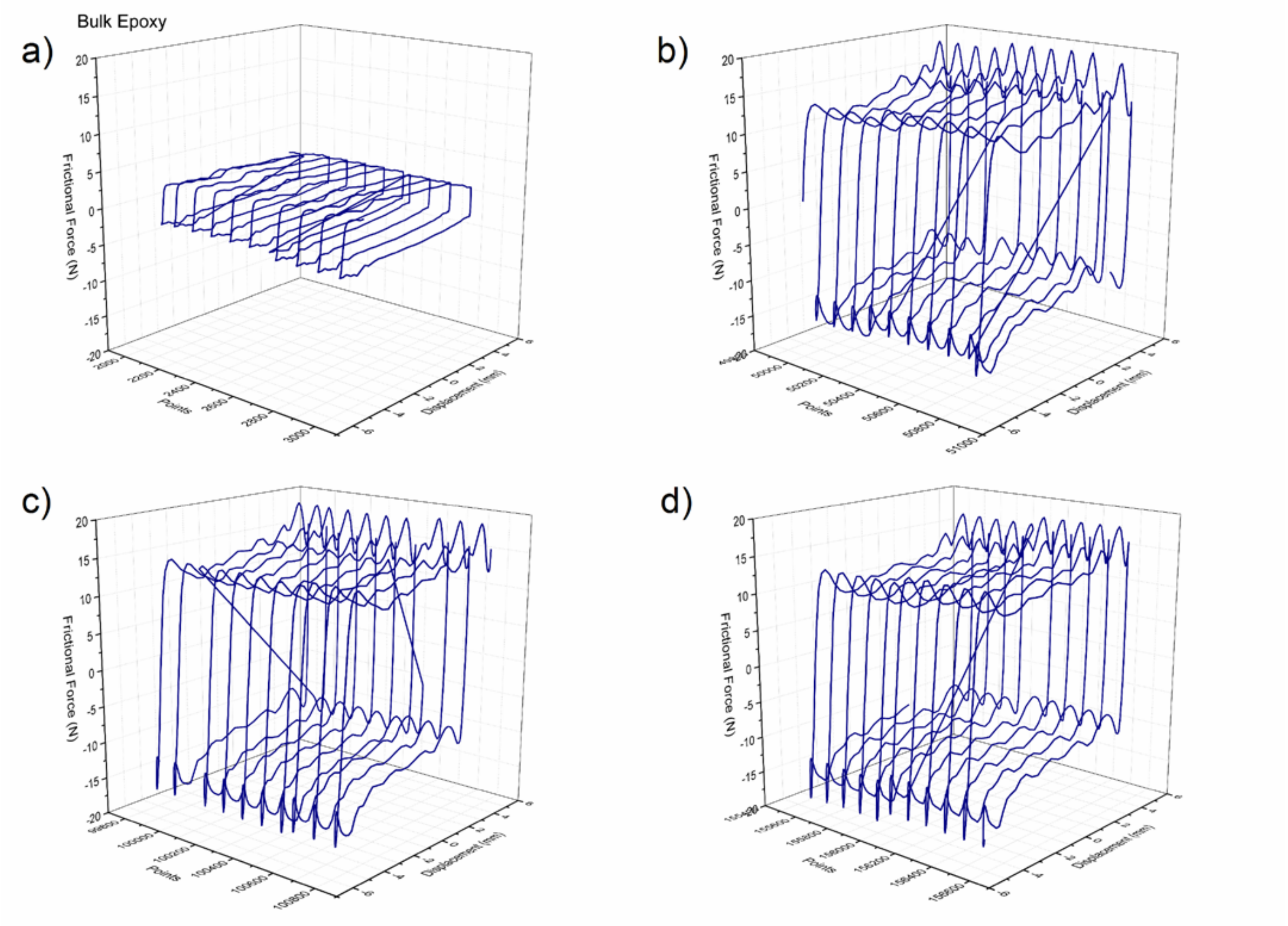

Figure 4: Evolution of the friction cycle during the test. Four time intervals were selected: (a) beginning, (b and c) intermediate, (d) final.

force corresponding to the static friction phase. The force rapidly decreases and is almost stable during the sliding moment, i.e. the kinetic friction. In Fig. 4 the typical evolution of the frictional force during sliding is represented. This figure is relative to a test executed on the bulk resin and four time intervals were selected as representative of the beginning, the intermediate and the final phases.

The main aspect that emerges observing these graphs is the differences between the beginning cycles and the others. In the first one, in fact, the frictional force is low and the transition between the static and the kinetic phase is not really marked. This phase is relative to the initial growing phase already observed in Fig. 2, afterward the friction is more stable and the cycles appear regular. There is anyway a noticeable non-symmetry between the two sliding directions, particularly in the two static phases, where the frictional forces are not always equal (considering their absolute values). Furthermore, irregularities in the acquisition procedure yielded to some misleading force behaviors, these inaccuracies are generated by lost values and by a linear interpolation made by the software, they are visible as straight transverse lines in the cycles and must not be considered. A comparison of the friction cycles among the different samples was also carried out, it was not found any significant dissimilarity apart from the obvious differences in the frictional force intensity, which follows the trend already described in Table I.

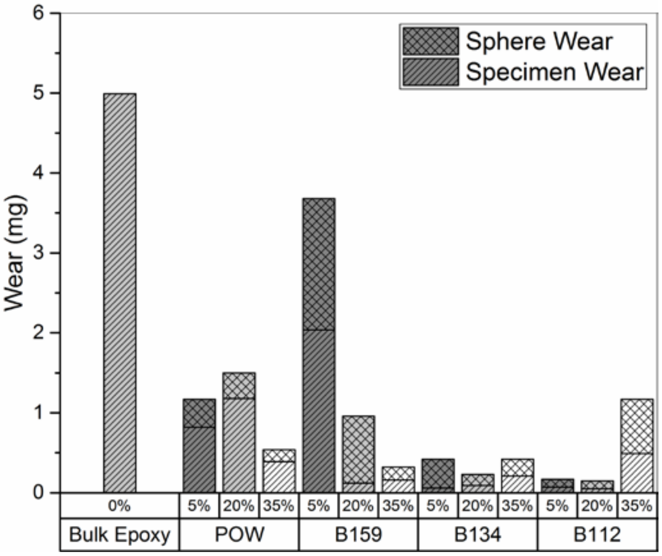

Figure 5: Wear of the specimen and the sphere.

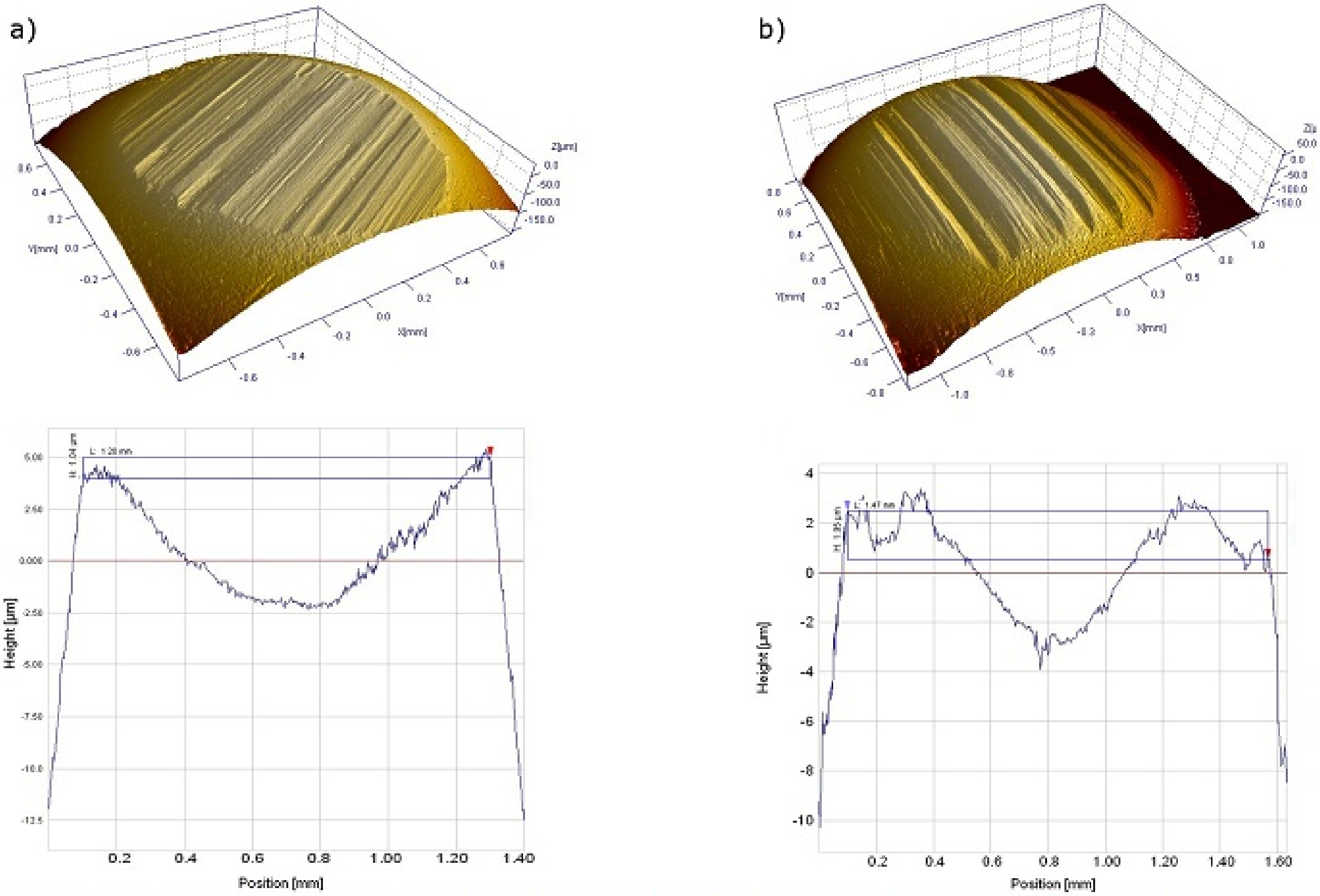

Figure 6: Three-dimensional scansions and profile of the surface of a titanium sphere rubbed against: a) B159 sample with 5 % glass vol. and b) POW sample with 5 % glass vol.

The results relative to the gravimetric analysis are summarized in Fig. 5, which shows the mass loss for both the specimens and the spheres and sums them up. Concerning the bulk epoxy, the wear of the specimen is the highest of all the investigation, equal to about 5 mg, nevertheless the wear of the sphere is the minimum quantity recorded. This behavior is well explained by the different hardness of the tribopairs materials. A similar response is recorded for the powder-reinforced resin.

On the other hand, in the beads reinforced samples, the main amount of mass loss is observed on the spheres rather than on the specimens. This is attributable to the abrasive wear process yielded by the glass beads acting on the titanium counterpart.

For the friction coefficient it was easy to identify a general trend, following the glass particle dimension, whereas for the wear the matter is harder. There is no particular reduction nor increment of this characteristic in dependence to the glass dimension and concentration. Furthermore, as observed for the µ evolution, the B159 5 % samples' results were in discordance with the others. Although the tests executed on this specimen gave a low friction coefficient, the wear was the highest among the reinforced epoxy specimens.

The main issue with the wear calculation is attributable to the high dependence of the weight loss by the glass particles bonding above the worn surfaces. After the tribotest, the worn surfaces were cleaned with ethanol, nevertheless many particles of glass – came out during abrasion – kept bonded on the epoxy surface. This occurrence yielded to a sizable uncertainty on the specimen wear evaluation.

Another way to evaluate the wear of tribopairs is through the surface profilometry, which produces qualitative and quantitative analysis of the worn faces [20]–[25]. Fig 6 is a composition of the 3D scansion of the worn surface of a titanium sphere and its bi-dimensional profile evaluated in the mid line. The bi-dimensional profile is obtained through subtraction of the fitted curve (a semi-circle), therefore it shows an equivalent profile relative to a plane profile with the same wear as the sphere. Acquisitions like the one aforementioned provided an indirect information on the volume loss on the sphere: by evaluating the diameter of the worn scar. Table I provides these diameters and compare them to the mass loss on the ball – already discussed in the gravimetric analysis –, it must be noted that the mass loss is not necessarily proportional to the corresponding diameter. This is due to different depths of the wear, as can be noticed in Fig. 6 where it is reported the 3D image of the ball worn area for: a) B159 5 % and b) POW 5 %. In the first case, the abrasive glass beads cut a sharp part of the sphere, whereas in the second one the worn surface is still spherical, entailing less mass loss. From the analysis of the worn area emerged an abrasive wear process, as the scars appeared parallel to the direction of the relative motion.

IV. CONCLUSIONS

In this work the tribological aspects of reinforced epoxy resin was investigated, by means of reciprocating friction and wear tests. The aim was to assess the opportunity to use glass waste to improve properties of the resin, and to investigate the influence of the glass particles, in term of dimension and volume concentration, on the friction and wear parameters. The main results emerged from this analysis are:

- the reduction of the friction coefficient as the resin is reinforced by glass beads;
- a correlation of the friction coefficient with the particles dimensions: μ decreased as the glass beads size grew;
- a slightly influence of the reinforcement volume fraction on the friction coefficient;
- a global reduction of the wear on the epoxy specimen as it is reinforced;
- an increment of the mass loss on the titanium spheres sliding against the reinforced samples, as effect of the abrasive wear;
- an higher wear depth on the titanium spheres sliding against reinforced sphere, not directly related to the scar diameter.

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