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Comment on "Surface Abrasion of Glazed Tiles"

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Esposito and Tucci have published recently an interesting paper on the assessment of surface abrasion of glazed ceramic tiles [1]. They studied the dependence of the wear behaviour of the glaze layer on several parameters such as porosity, hardness and fracture toughness of the glaze. Six single-fired glazed ceramic tiles were chosen for the experiments. The wear behaviour was assessed by measuring the material removal resulting from the standard PEI abrasion test, determined after two stages of 6000 and 12000 revolutions. A summary of the materials investigated, including hardness (*H*) and fracture toughness (K^{Ic}) measured on the glazes and data on wear behaviour, given both as PEI classification and normalised weight loss, is given in Table 1.

The work confirmed that the standard PEI classification is insufficient to differentiate the wear behaviour of ceramic glazes. While the materials investigated fall into only two PEI classes, they exhibited markedly different wear resistance, with sample 2 clearly showing the lowest material loss.

The results of Esposito and Tucci also showed that the wear behaviour of the glazes could be correlated with their fracture toughness values. This behaviour is shown in Figure 1, indicating that wear resistance increased with increasing fracture toughness (in other words, normalised weight loss decreased with increasing fracture toughness). Due to the fact that the hardness of all samples was nearly identical (Table 1), the authors concluded that this property would not affect the material removal during abrasion test [1]. The present comment has been prompted by this last conclusion of Esposito and Tucci [1], which seems to suggest that fracture toughness is the only property affecting wear response of glazed tiles.

In fact, in studies of the wear behaviour of engineering ceramics, the comparison of wear resistance parameters (e.g. wear rate or volume of loss material) with hardness or toughness values taken separately has not always resulted in clear, unambiguous correlations [2-4]. On the basis of fracture mechanics analysis, the product $K^{Icn}H^{m}$ has been suggested to be related to the wear resistance, with the exponents *n* and *m* depending on the mechanisms of material removal: *n*=3/4 and *m*=1/2 being applicable for abrasion and *n*=4/3 and *m*= 1/4 for erosion [5,6]. Comparison of experimental data on engineering ceramics and ceramic composites with the prediction of these models has not been always successful and discrepancies have remained [7-9]. Independently of the material removal process involved, when the exponents in the fracture mechanics expression take the values *n*= -1 *m*= 1, the aforementioned product yields the so-called "brittleness index" (*B*) of the material [10]. We have suggested in a recently article the use of the brittleness index (*B*) for a qualitative estimation of the wear and

TABLE 1: GLAZES INVESTIGATED BY ESPOSITO AND TUCCI [1] AND THEIR PROPERTIES

Sample	PEI class	Normalised weight loss [μg/mm^2] (6000 rev.)	Normalised weight loss [μg/mm^2] (12000 rev.)	Hardness [GPa]	Fracture toughness [MPam$^{1/2}$]	Brittleness index [μm$^{-1/2}$]
1	IV	19.63	44.47	5.6	1.00	5.60
2	IV	1.56	3.01	5.5	1.23	4.47
3	IV	17.85	33.90	5.5	1.13	4.86
4	II	26.28	51.89	5.7	0.92	6.19
5	II	29.57	55.00	5.4	0.81	6.67
6	II	26.39	57.13	5.6	0.80	7.00

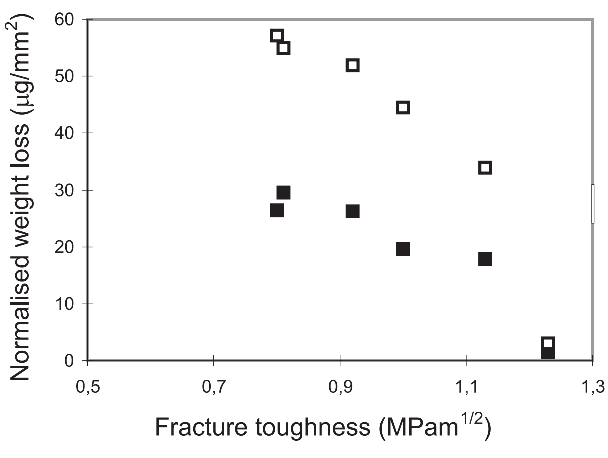

Figure 1: Normalised weight loss as a function of the fracture toughness of the glaze layers. 6000 rev. (■), 12000 rev. (□), according to the results of Esposito and Tucci [1].

erosion resistance of engineering ceramics and ceramic composites and for classifying these materials in terms of the material removal mechanisms during wear and erosion [11].

Brittleness is a measure of the relative susceptibility of a material to deformation and fracture [10], relating hardness, which quantifies the resistance to deformation, and toughness, which quantifies the resistance to fracture. The brittleness index *B* varies between ≈ 0.1 $\mu m^{-1/2}$ for steels and ≈ 17 $\mu m^{-1/2}$ for Si-monocrystal, with values for glasses and ceramics varying in general in the range 2-9 $\mu m^{-1/2}$ [10]. In principle, all processes involving simultaneously deformation and fracture in brittle solids should be possible to be described, at least qualitatively, in terms of the brittleness index. For example, the grindability and machinability of glass-ceramics can be correlated with their *B*-values [12]. This correlation was shown to be better than that existing between machinability and hardness or machinability and fracture toughness [12, 13]. Since wear and erosion processes in ceramics involve in general both deformation and microfracture [9], we postulated that the brittleness index, combining both material's responses, should be a better parameter for their quantification than hardness or fracture toughness taken separately [11]. Moreover, the index *B* should provide a tool for assessing the wear and erosion resistance of ceramics and its value should also indicate which material removal mechanism is preponderantly taken place.

The brittleness index data for the glazed tiles investigated by Esposito and Tucci are given in Table 1. Figure 2 shows the variation of the normalised weight loss with brittleness index for the six samples investigated at two different numbers of revolutions. The data show that with increasing brittleness index the wear resistance of the glazed tiles deteriorates. This result is in agreement with data analysed by the author of this note on different engineering ceramics [11]. Figure 2 also confirms that the brittleness index (*B*) is a suitable parameter to assess the wear behaviour of glazed tiles as there is a high correlation between brittleness index and normalised weight loss data. Indeed, since the hardness of the considered samples is nearly identical, this result is not surprising, and it is equivalent to that expressed in Figure 1 for the variation of wear resistance with fracture toughness.

Thus, due to fact that the samples investigated exhibited too close hardness values (Table 1), the results of Esposito and Tucci do not yield a definitive answer to the original question as of which material property is more appropriate to predict wear behaviour of glazed tiles, whether fracture toughness or brittleness index. It may be even speculated that the good correlation between fracture toughness and wear behaviour data obtained by Esposito and Tucci is fortuitous and simply the result of having investigated samples with nearly identical hardness. Since the PEI test seems to be insufficient for an accurate classification of wear behaviour of ceramic glazes, as demonstrated by the results of Esposito and Tucci [1], further research in this area aimed at clarifying the relationship between wear resistance, hardness, toughness and brittleness of glazes is encouraged. The objective should be to identify the property, or combination of properties, most suitable to be used as a tool for prediction of wear behaviour of ceramic glazes. We are currently conducting research on glazed tiles exhibiting very different hardness and fracture toughness values, in the ranges 6-7.5 GPa and 1.2 – 3.3 $MPam^{1/2}$, respectively [14], in order to verify our hypothesis that brittleness index is a better indicator than fracture toughness or hardness taken separately for the assessment of wear behaviour of glazes.

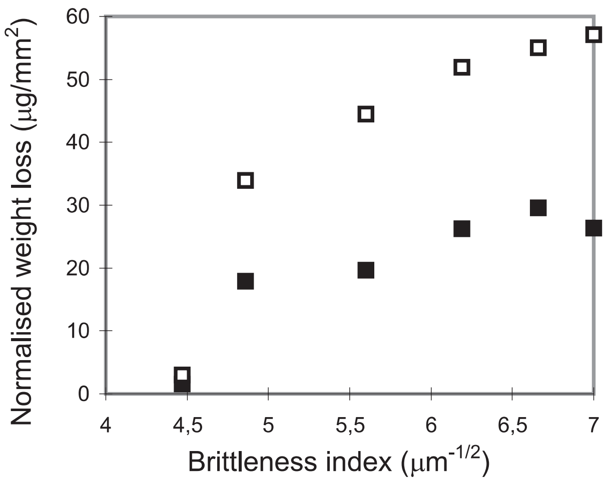

Figure 2: Normalised weight loss as a function of the brittleness index of the glaze layers. 6000 rev. (■), 12000 rev. (□).

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