Influence of the Petrographic Characteristics on the Industrial Polishing of Ornamental Granites Slabs

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Abstract. The polishing of ornamental granites is characterized by the abrasion between the rocky surface and an abrasive tool, which is the cutting element that is often composed of Silicon Carbide (SiC). The interactions between the mineral phases and textural characteristics of the rock with the abrasive properties (hardness, forms, size, etc.), together with the operational variables of the polishing machine (load stress, sawing speed, etc.) make up a system denominated by Mechanical Engineering as the Tribologic System. This paper presents an analysis of the surface roughness of three Brazilian granites subjected to the same industrial surface treatment process. After analyzing the data obtained, two main types of roughness were defined: the first is a low amplitude roughness related to the roughness of the mineral surface (denominated “Mineral Roughness – MR”) while the second, with larger amplitudes, exhibits the contacts between minerals or cracks at the surface of the mineral, mainly according to the direction of the cleavage plans in which more accentuated depressions will probably develop (denominated as “Contact Roughness – CR”). Throughout the polishing stages of the three rocks, the MR value was that which displayed a decrease, with CR showing a small difference. The CR value is intimately related to the degree of anisotropy of the rock. The verification that different petrographic characteristics respond in a singular way to the same load of a certain industrial process proves that the rock has an active role in its interaction with the abrasive properties and the operational variables of the polishing equipment (Figure 1). Such approach opens a research field that uses Tribology concepts to better understand the polishing process of dimension stone.

Introduction

Developed countries with a pronounced participation in the dimension stone industry (Italy, France, Spain, among other), besides being traditional industries in this section, dominate extraction techniques, treatment and equipments production. Brazil, besides having presented a significant improvement in operational quality of its industrial parks, mainly referring to the primary and secondary treatment techniques, it has not yet made any important attempt to carry out intensive research in this important section of the economy [1, 2, 3, 4].

One of the research stages which has been lacking, but has only been treated empirically is that regarding the process of polishing of rock slabs. The understanding of this process as a process of surface wear in which there exists an intimate relationship between many variables is still not complete. The intrinsic characteristics of the rock [5, 6, 7, 8, 9, 10], the types and forms of abrasives [11, 12, 13] are some of the factors that have a major influence on the final product and that which, almost always, are relegated to rare. In many cases, the method of approach to this process approaches that adopted by “Tribology ” [14, 15], branch of mechanical engineering that studies the wearing mechanisms in metallic alloys. It is thus in this framework that any research work of this nature is considered to provide an effective contribution in the knowledge of the wearing mechanisms in real material such as rock when subjected to polishing.
Objective

The main objective of the present work is to analyze the behavior of different rocks subjected to identical wear situations. The research study aims at showing that the quality of the polishing of dimension stone depends, to a higher degree, on the intrinsic characteristics of the petrous material.

Experimental Procedures

Petrographic analyses of thin section obtained from the rocks under study were carried out based on the European Committee for Standardization code guidelines [16]. The main petrographic characteristics of the rocks studied are shown below (Fig. 1).

The “Indian Black” – is a migmatite with folded structure, showing different intensities of foliation responsible for higher or minor degrees of parallelism between the paleossomic and leucossomic levels. The paleosome shown present dark gray color, tonalitic composition, made up mainly of andesine/oligoclase (41.0%), quartz (22.0%), biotite (23.0%) and microcline (4.5%), besides sillimanite (5.0%) and muscovite (3.0%), and frequently to a lesser degree, garnet (1.0%) and cordierite (0.3%). The secondary minerals (0.2%) are opaques, zircon, carbonates, sericite and clay minerals. It also presents a granoblastic to granulpidoblastic texture of medium grain size, predominantly between 1.5 and 4.0mm. On the other hand, the leucosome presents a whitish color and a monzogranitic/monogranitic composition made up essentially of andesine/oligoclase (40.0%), quartz (32.0%), microcline (25.0%) and biotite (3.0%). Leucosome is also found to present a hypidiomorphic-granular texture with an average (2.0 a 4.0mm) to medium/coarse (5.0 to 10.0mm) grain size.

The “Brasília Red” – is a sienogranite of equigranular reddish coloration. It presents a hypidiomorphic-granular texture, with a coarse grain size which ranges from 3mm to 50mm, predominantly between 5 to 30mm. Its essential minerals are quartz (32.0%), microcline (41.0%), oligoclase (16.0%) and biotite (5.0%); with accessories (2.0%)-opaques, zircon, carbonates, sericite, chlorite, iron hydroxides, and secondary minerals (<4.0%)-sericite, muscovite, epidote, chlorite, carbonates, clay minerals and iron hydroxides. It also presents a good mineral imbrication giving a high cohesion to this rock.

The “Castle Gray” – is a monzogranite of gray coloration and massive, isotropic structure. It presents a hypidiomorphic-granular texture and a coarse grain size which ranges from 3mm to 50mm, predominantly between 5 to 30mm. Its essential minerals are quartz (29.0%), microcline (34.0%), oligoclase (22.5%) and biotite (8.0%); with accessories (1.8%)-opaques, titanite, allanite,
apatite, zircon, fluorite and secondary minerals (4.0%)-sericite, muscovite, clorite, epidote, carbonates and clay minerals.

Considering the degree of microcracking and mineral alteration of the three rocks studied, some similarity was observed to exist between the migmatite-“Indian Black”, sienogranite-“Brasília Red” and monzogranite-“Castle Gray”. For these rocks, the observed degree of microcracking is low. The intergrain and intragrain microcracks length is also shown to be small, microcracking being more frequent in the large crystals, predominantly those of feldspar and quartz. The observed mineral alteration is weak to moderate and is characterized by the visible argile-mineralization, mainly of the feldspar crystals (plagioclase).

Measurement of the roughness of the rock slabs

Statistica 8.0 and Excel 2007 software programs were used to generate the surface curves from absolute values the Talysurf 1205 roughness model. The data reading step was put on the abscissas and values of height, in absolute values (measured in microns) on the ordinates. Approximately 800 points were measured to generate each curve.

After a close analysis of the data obtained, two main types of roughness were defined: the first being a low amplitude roughness related to the rugosity of the mineral surface and denominated “Mineral Roughness – MR”) while the second with larger amplitudes reflects contacts between minerals or cracks at the surface of the mineral, mainly according to the direction of the cleavage plans in which probably more accentuated depressions develop (denominated as “Contact Roughness – CR”).

Roughness of the rock slabs

FIRST STAGE (#24MESH)

During the first wearing stage, it is easy to notice the clear influence of the lithological properties on the response of the rock to wearing loads due the machine and abrasive. The surface of the migmatite-“Indian Black” is observed to be more irregular, reflecting the anisotropy of this rock showing an alternation of granoblastic and lepidoblastic levels (Fig. 2A). In both the profile related to this material and that of the sienogranite-“Brasília Red” it is still not possible to determine which portion of the profile really represents the surface roughness of a mineral and which is an intergrain contact. In the subsequent stages, mainly in the case of sienogranite-“Brasília Red”, this distinction is more clearly defines (Fig. 2B). In the subsequent stages it is possible to notice the marked decrease in streak intensity left by the abrasive on the surface of the rock. The Maximum Amplitude (R_{max}) observed in the roughness profile of this material, during the first phase of wear, is 500 µm, inferring that finer rocks tend to present better finishing. The fine texture of monzogranite-“Castle Gray” imposes a natural decrease in intergrain contacts, or in a certain way, it camouflages such contacts and as such confuses them with planes of mineral roughness. Together with this, the fact of this rock to be considerably isotropic hinders even more the differentiation of the two types of roughness (Fig. 2C).

![Figure 2](image-url)

Figure 2 - Roughness profiles on the first wear stage: (A) migmatite-“Indian Black”; (B) sienogranite-Brasília Red” and (C) monzogranite-“Castle Gray”.
SECOND STAGE ( # 36 MESH)

In this stage, the roughness profile of the migmatite-“Indian Black” shows a higher tendency in generating the separation among the two types of roughness proposed in this work, although this separation is still not clear. This means that the streaks resulting from the abrasive are still larger than a possible difference in mineral surface roughness or contact between grains (Fig. 3A). With exception of one point, the MR values are found to approach 1100 µm. Due to the small variation in grain size distribution of the abrasive compare to the previous stage, the resulting marks in this stage present the same behavior with the only difference being a reduction in the original groove area after block sawing. During this phase, the “Brasília Red” sienogranite was found to present marked decrease in MR values, reaching approximately 600 µm (Fig. 3B). It is possible to note the isotropic structure of this material from the roughness profile. During this phase of wear phase, the surface of “Brasília Red” sienogranite presents strips resulting from the polishing abrasive, however, it is found to be free from the irregularities originating from of sawing. From the first to the second phase of wear, the monzogranite- “Castle Gray” paws shown to present a decrease in R_{max} of the order of 100 µm attaining approximately 400 µm at this stage. It is easy to notice strips (scratches) caused by the abrasive intensely marked on the biotite blades and the low amount of intergrain microcracks (Fig. 3C).

THIRD STAGE ( #60MESH)

The third stage of wear is considered the last wearing phase and consists of a very intensive removal of material and precedes the levigation stage (#120) thus representing the stage where the intensity of the rate of wear changes. During this phase, the migmatite-“Indian Black” is shown to present a roughness of approximately 600 µm with the separation between MR and CR capable of being seen under a high resolution (Fig. 4A). This can also be possibly notice from the images of sample surface which evidence a difference in behavior when the micaceous domain is compared to the granular domain. During this phase, the sienogranite-“Brasília Red” continues to maintain a higher homogeneity in its roughness profile (Fig.4B). The observed MR values were around 250 µm, which represent a surface 3 times less roughness compared to migmatite-“Indian Black” in the same wear phase. Except for two points in the roughness profile, the monzogranite-“Castle Gray” presents a R_{max} of the order of 200 µm, translating in a reduction of practically 50% in this parameter relative to the previous phase (Fig. 4C). The largest depressions are caused by intergrain microcracks situated mainly inside plagioclase crystals and secondarily in quartz crystals.
FOURTH STAGE (# 120 MESH)

The Stone Industry has defined this stage empirically as being the ideal moment for the resin treatment of slabs. From a close look at the roughness profile of the migmatite-“Indian Black” (Fig. 5A), it is possible to notice that for the first time, a separation between MR and CR occurs. This well defined separation is due mainly to the fact that the compositional bands that occur in this material respond differently to load imposed by the polishing process as well as the decrease in the abrasive grain size distribution. Having clearly distinguished these two roughnesses, any analysis or focus on the interpretation of the roughness data must consider both as irregularities which reduce surface planicity thus interfering in the final rock brightness. However, it is important to remind that the first type of roughness which is subtle and found only on the mineral surface is more related to the polishing process while the other with higher $R_{\text{max}}$ values is related to the genetics characteristics of the rock. From this point onwards, the term “Mineral Roughness” will be employed in reference to mineral surface roughness while for higher roughness resulting from the contact between minerals, the term “Contact Roughness” will be employed. During this phase a sensitive decrease in MR values which vary within 150 $\mu$m is observed while CR attains a value of 1300 $\mu$m for the migmatite-“Indian Black”. In the image referring to migmatite, a clear decrease in the size of the grooves due to the abrasive is noticed. However the micaceous portion (weaker) begins to suffer scaling by lose of mica lamellas that can be responsible for an increase in CR. This scaling, in most cases, is the result of an increase in the pressure of the polisher headstock and it can justify the occurrence of an anomalous depression in the roughness profile in weaker materials. In the case of the sienogranite-“Brasília Red”, the values of MR presented are approximately 300-400 $\mu$m (Fig. 5B). Because this rock contains essentially quartz and potassic feldspars in its mineral composition with little amount of mica, it shows a much more constant pattern in its roughness profile. Coupled to this mineralogical factor, its highly isotropic character in relation to the migmatite-“Indian Black” aids in maintaining such constancy. At this stage, the monzogranite-“Castle Gray” was shown to present a general decrease in roughness along its entire profile, the greater part being located within values lower than 200 $\mu$m (Fig. 5C). The main discontinuities are intergrain microcracks observed in the plagioclase crystals.
**Discussion**

In the initial stages of wear, the roughness profiles of “Indian Black” migmatite are observed not to show any clear separation between MR and CR, the latter, for this rock, being observed to occur between the micaceous and granular levels. This occurs due mainly to the abrasive stages which leave very prominent streak and to the depressions inherited from the sawing process.

Considering the granites “Brasília Red” and “Castle Gray”, in the first stages of wear, it can be inferred that: in principle, rocks considered “hard” when sawed, tend to present slabs with more surface imperfections, mainly due to the fact that the advance of the gangsaw in these types of granites is slower. When such a material is subjected to polishing, the grooves obtained from the sawing tend to be more intensive compared to weaker materials. This behavior is reflected in the roughness profiles which show few abrupt variations in MR. Such an aspect is also related to the high isotropy compared to the migmatite—“Indian Black”.

The Dimension Stone Industry defines the wear due to the #120 mesh abrasive as the most appropriate moment for the resin treatment of slabs. This treatment consists in placement a film of epoxidised resin to obtain an efficient closing of the pores and consequently an increase in the final brightness. From a close look at the roughness profile of the migmatite—“Indian Black” during this phase, it is possible to notice that, for the first time, there is a separation between MR and CR. This clear separation is due mainly to the fact that the compositional bands found in this material respond differently to load imposed by the polishing process as well as to the decrease in abrasive grain size distribution. Having differentiated these two roughnesses, any analysis or focus to be given in the interpretation of the roughness data should consider both as irregularities which reduce the surface planicity thus interfering in the final brightness of the rock. However, it is worth reminding that the first type of roughness, subtle and limited to the mineral surface, it is more related to the polishing process while the other, with a more pronounced Mineral Roughness is related mainly to the genetic characteristics of the rock.

One factor that turns out to have more participation generating irregularities from the beginning of the fourth stage of wear is mineral cleavage. In the case of the potassic feldspars present in “Brasília Red” sienogranite, they are often the largest grooves present in the rock since the streaks left by the abrasives from the start of this phase are expected to be smaller than such mineral features. It is possible that different rocks present more ideal stages wear for resin treatment. The levigation, defined by the #120 mesh, abrasive may or may not be the most appropriate depending on the petrographic characteristics of the given rock before or after this phase.

At each stage of wear, the values of MR and CR for the “Indian Black” migmatite become more and more distant. This is due, firstly, to the mineralogical factor since this rock presents minerals with properties which are different from each other coupled to the fact that its band structure which, despite the decrease in granulation of the abrasive, is expected to continue interfering in the final roughness.

From the intermediate phases of polishing, there is preferential development of cracks associated to the garnet crystals present in “Indian Black” migmatite, which may cause the detachment of crystals fragments of this mineral responsible mainly for the generation of depressions in this rock. Besides this, the grenade fragments can still cause problems during polishing since they are on the surface of the slab. The fragmentation of the grenade crystals must therefore considered form the second half of the polishing process.

From start to the end of the polishing process, it is estimated that about 1000 µm (1 mm) in thickness of the rock is consumed. This explains the decreasing RC values with the polishing stages.

**Conclusion**

The obtained results showed that different types of rocks respond to load imposed by the couple abrasive/polishing machine in a specific way which is a function of their intrinsic characteristics. During all the polishing stages of the two rocks, the value of MR was that which presented a decrease with CR showing a small variation. The value of CR is intimately related to the degree of
anisotropy of the rock. Any attempt to carry out polishing with the aim of reducing these types of irregularities is thus an important step towards the quality improvement in the secondary treatment of dimension stones.

Adopting an approach in which it was possible to define an integrated system of variables which have an influence on the rock polishing allowed us to fully understand wearing phenomena which occur at this industrial stage. The possibility to adapt the Science of Tribology which studies friction and wearing mechanisms is a good option for any theoretical base concerning the theme since the polishing of dimension stone fits in the framework of the two-body abrasive type wear Tribology (abrasive tool and rock), the third element being made up of the polisher including its operational variables.

References


