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Mechanical, Thermal and Rheological Characterization of marble waste with Different Coolants

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Abstract

The mechanical properties of Andhi white marble sample is evaluated according to ASTM standards, then X-Ray diffraction analysis was carried out to find out the chemical composition of the sample, further the sample is thermally characterized using TGA analysis in order to find out the weight loss %, then the marble powder obtained after machining process through circular sawing is characterized rheologically using different coolants to find out the behaviour of marble powder. The chemical composition test with XRD revealed the presence of Quartz as the major constituent in all the marble and with other elements like Lime, Priclase and Hematite.

For rheological characterization, several mixtures were prepared using marble powder and different coolants with different ratios. Bingham flow model was used to plot mean values of yield stresses on different samples plotted as a function of time showed highest value of yield stress for marble/water ratio of 0.5.

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Keywords: Natural stone; Mechanical testing; Rheological characterization; TGA analysis; XRD analysis.

1. Introduction

Marble is widely used in construction and building materials since ancient times. Disposal of this waste either in the form of powder or aggregates is causing environmental problems throughout worldwide. It is well known that there is variousness in this waste generation one: waste generated from quarries and two: from processing plants [1]. Further, two more type of wastes generated through processing plants: solid waste and semisolid waste or slurry [2]. Frame cutting with diamond blades is a commonly used machining technique especially by small scale industries, in which water is widely used as a coolant and the powder generated blends with water to form viscous slurry [3]. These

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diamond segments are brazed to the steel frame and sawing of the marble block is carried by reciprocating this frame [4]. A frame blade can hold 25-30 blades with length 3000-4000 mm. It almost takes 8-12 hours to split these marble blocks to required dimensions. As the cutting process takes place continuously for many hours wearing of the tool takes place and there are great chances of entrapping the slurry in that worn out surfaces of the tool bits. The Scanning electron microscopy pictures of the worn out surfaces tested also revealed the deposition of the slurry layer [4]. This may affect the cutting process like changing the cutting force or the surface finish of the cutting face of the marble. This slurry which is a semisolid waste generated due to cutting of marble is diverted to the sedimentation pits or sedimentation and filtration towers shown in Figure 1. This waste generated has a rigorous impact on environment in both the locations: quarries and processing plants. In quarries, the extraction of rock process is accompanied by dust contaminating the air in addition and the excavation areas leaving adverse effect on landscape and soil. In processing plants as water is used as coolant partially removes the air contamination but on the other note it causes the water contamination and forms big basins of mud.

This waste which is in the form of powder as well as aggregates is used widely nowadays as partial substitution of cement, and partial substitutions in concrete with different water to cement ratio [5]. The marble powder acquired as a result of marble cutting and processing, was characterized physically and chemically to check the probability of using it in mortar and concrete production [6].


(a)


(b)

Fig. 1. (a) Sedimentation pits, (b) Sedimentation and filtration towers

2. Investigation Connotations

In this study the marble Andhi obtained from quarry was characterized according to the ASTM standards to find its physico-mechanical properties, and then XRD analysis was done to find out its chemical composition. Further, the powder obtained from cutting is thermally characterized using TGA analysis to find out its peak temperature and weight loss %and then it is characterized rheologically using different coolants to see the behaviour of the slurry using water to coolant ratio (W/C) as 0.5. This research is intended to find out the possible coolant which helps in reducing the viscosity of the slurry so that it may not stick to the tool while sawing.

3. Materials and method

Following experiments were performed to determine the physico-mechanical properties according to ASTM standards

3.1 Water absorption, Bulk density and bulk specific gravity

Water absorption, Bulk density and bulk specific gravity testing of marble was determined according to ASTM C97 test standards

3.2 Compressive Strength testing (ASTM C170)

Compressive strength testing of the marble sample was determined according to ASTM C170 test standard.

3.3 Modulus of Rupture (ASTM C99)

Modulus of rupture of marble sample was determined according to ASTM C99 test standards. A single point load was applied exactly at the centre of 180 mm length. Almost 5 to 10 samples were tested in wet and dry conditions and load is applied both parallel and perpendicular to the rift plane.

3.4 Flexural Strength (ASTM C880)

Flexural strength of the marble samples can be determined according to ASTM C880 test standard. In this testing method marble samples were first cut in large slabs. Then, load is applied at the quarter point of these specimens. This load is increased continuously until these samples got fractured. The maximum load at which the fracture occurred is recorded and also the flexural stress that occurred at this load is also recorded. Five samples were tested both in dry and wet conditions as well as both parallel and perpendicular to the rift plane. So, according to the experiments performed the physico-mechanical properties are listed in Table 1 below.

Table 1 Physico-mechanical properties of Andhi marble

Type of Stone	Water absorption (% by weight)	Density (g/mm^3)	Modulus of Rupture(N/mm^2)		Compressive Strength (N/mm^2)		Abrasion	Flexural Strength (N/mm^2)
			Dry	Wet	Dry	Wet		
Andhi	0.08	2.83	14	17	94	114	4.1	16

3.5 Chemical and XRD analysis of the Andhi sample

To characterize the sample from thermal and chemical view point, thermal study and X-ray diffraction were carried out. Thermal test conducted illustrated that the examined powder contains 44% of calcium carbonate (CaCO3). This can be observed from Figure 2 a sharp loss in weight occurs with a peak temperature of 8240 C. This loss in weight occurs due to the decomposition of the calcite can be seen from the Figure 3 of X-ray diffraction patterns with small amounts of quartz, Lime, periclase, hematite and alumina. A chemical composition test using titration method is also performed to know different constituents present in the marble are shown in Table 2.

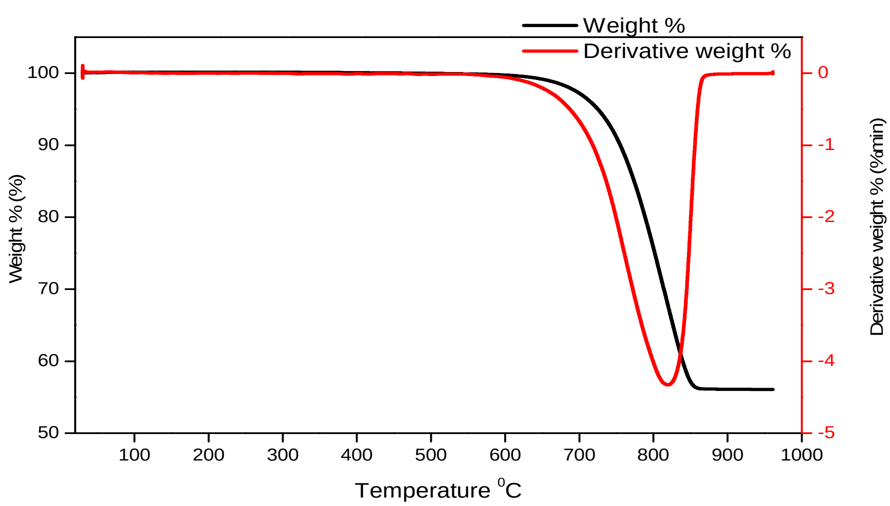

Fig. 2. Result of thermogravimetric (TGA)

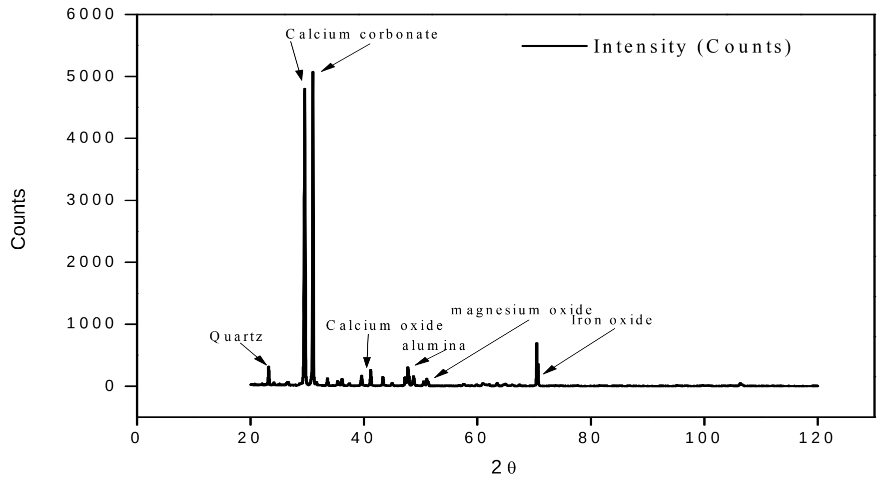

Fig. 3. XRD pattern of the marble sample

Table.2 Chemical composition of Andhi marble

Component	**Values**
SiO_2, Quartz	3.17
CaO, Lime	43.89
MgO, Periclase	8.91
Fe_2O_3, Hamatite	0.3
Al_2O_3, Corundum	Traces
LOI	43.71

4. Rheological behaviour with different coolants

The rheological study of marble slurry is a vital characteristic for the calculation of marble characteristics, and for the parameter optimization. To achieve this, four marble sample pastes were made ready by keeping the powder to coolant ratio constant i.e 0.5. All rheological experiments were carried at room temperature (25°C).The amounts of these slurry mixtures are shown in Table 1

Table.3 Marble powder Mixtures and their Proportions.

Mixture	Marble Powder (g)	Coolant (g)
Marble Paste + Water	10	5
Marble Paste + EDDG Oil	10	5
Marble Paste + EDM Oil	10	5
Marble Paste + Cutting fluid	10	5

Fig.4 Sample preparation with different coolants

Fig.5 Rheometer setup

The rheological study of these marble pastes were carried out at every 15 min after components mixing, and carried out till one hour. The apparatus used for the experimentation is a rotational rheometer built on coaxial rotary chambers with gradually increasing shear rate (D), extending from 1 to 100 s-1, the setup is shown in Figure 5

Bui et al. [7] experimented and determined that the shear rate of 1–100 s-1 was the best appropriate for rheological study of cement mixes, while large shear rates were considered too fast and rates limited to 50 s-1 did not yield constant results. The time requisite for the up-curve was one and half minute, for it to reach maximum shear rate of 100 s. The walls of the rotating rheometer is made of concentric chambers (the gap between camber walls is kept 5 mm) and the inner surface is coarsened in order to decrease (if not completely remove) the ‘‘slip” phenomenon; i.e., the progress of water-rich layer close to the inner surface of the rotating cylinder, is to produce a greasing effect, making flow easier, for the bulk material [8].

Rheological behaviour is usually defined by means of the Bingham flow model. This model assumes the marble paste behaves like a rigid body before a critical shear stress value is reached, called the yield point, beyond which it behaves like a Newtonian fluid. The shear stress at this yield point is defined as the yield stress (y, a critical value at which the properties change from rigid solid to a viscous liquid. The yield stress obtained from this model is dynamic yield stress, which is the intercept of the high shear rate asymptote with the shear stress axis. The shear stress vs. shear rate (relationship according to Bingham Plastic model is expressed as follows:

$\tau = \tau_y + \eta \dot{\gamma}$ for $\tau > \tau_y$ where η is the viscosity of the fluid.

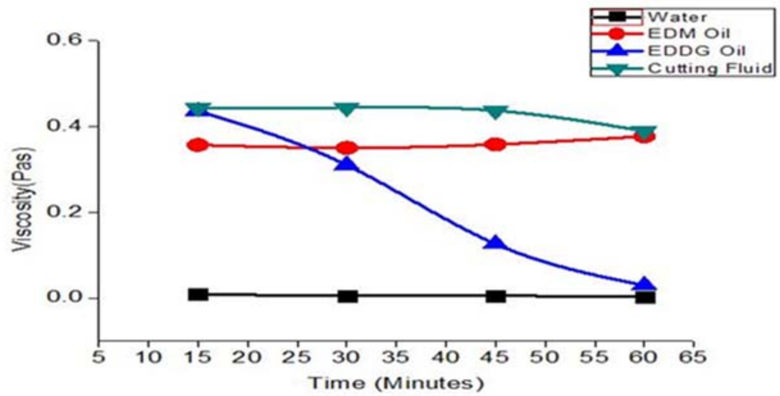

Fig.6 Yield stress values plotted against function of time

In Figure 6 the mean rate of the yield stress values on four samples are represented as a function of time. It is obvious that the paste made of marble powder, and Electric Discharge diamond Grinding (EDDG) oil of 0.5 exhibited the highest values of the yield stress, in the range of 10.5 to 15.3 Pa. Quite large values were acquired for the pastes made with fine powder and water ratio below 0.5 ratios. On the other hand, when the water to marble ratio was kept 0.5, even at the low value (0.5% by weight of marble), the yield stress was found to be uniform on each time interval, thus inferring low cohesiveness of the related marble. Lowest yield stress values -2.179 Pa was observed for marble to Electric Discharge Machine (EDM) oil mixture.

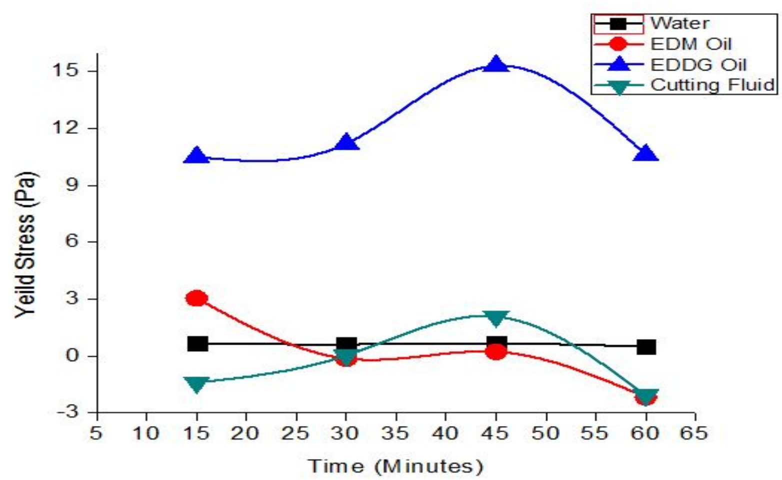

Fig. 7. Mean values of plastic vs function of time

In Figure 7 mean values of the plastic viscosity of four samples were plotted against time. A uniform plastic viscosity at different time intervals was observed in the paste prepared with water as coolant. In this study a higher value of viscosity 0.444 Pa-sec is observed with cutting fluid paste, and lowest value of viscosity of 0.0027 Pa-sec was observed in the paste prepared with water as coolant.

5. Harshal Bukley Model

Marble pastes prepared for experimentation behaves as Non-Newtonian fluid and the behaviour of the fluid when tested shear thinning affect is caused for the fluid. The same phenomenon is exhibited by the Harshal Buckley Model which is a generalized model for a Non-Newtonian fluid, in which the strain exhibited by the fluid is associated to the stress in an intricate, non-linear way. Three factors generally used to characterize their association: the consistency k, the flow index n, and the yield shear stress (τ_0). The uniformity is a simple constant of proportionality, while the flow index measures the degree to which the fluid exhibits shear-thinning or shear-thickening.

The main equation of the Herschel-Bulkley model is commonly written as

$$\tau=\tau\_0+k\dot{\gamma}\hat{}n$$

Y=a+b.Xp

a = Yield Stress, Y=Shear stress

X= Shear rate

b consistency index and p flow index

For p<1 the fluid is shear-thinning, whereas for p>1 the fluid is shear-thickening.

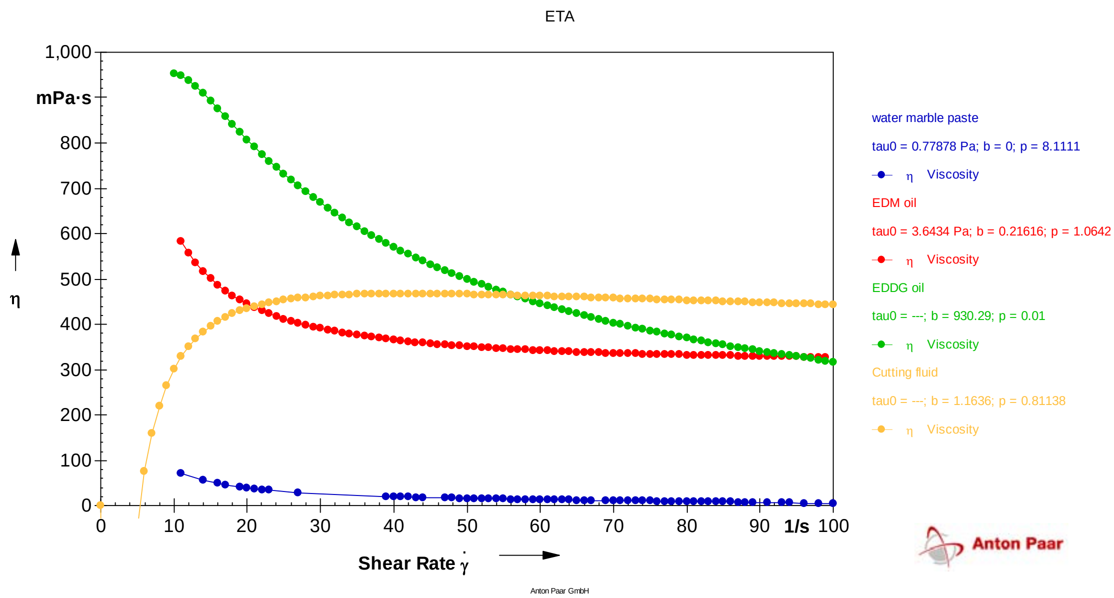

Fig. 8. Comparative for Harshal Bukley behaviour of marble paste at different coolants and temperature

Figure 8 shows the comparative graphs of shear thinning nature of paste mixed with different coolants. Highest change in viscosity with shear rate is observed in EDM oil and marble powder.

6. Conclusions

Marble slurry obtained by cutting process has high viscosity. As, this process continues uninterrupted for long hours this slurry dries up and shear thickening occurs. This thickened slurry sticks to the newly emerged diamond particles and deteriorates the surface. The main aim of this paper is to identify a coolant whose viscosity decreases or shear thinning occurs. After the series of experiments performed using different coolants, with the marble powder the following conclusions can be drawn.

a) TGA investigation carried out resulted that the powder contains 44% of calcium carbonate $CaCO_3$ and it is stable till 8240 C.
b) X-Ray diffraction patterns show the presence of quartz, lime, hematite and alumina.
c) Marble paste mixed with Electric Discharge Diamond Grinding (EDDG) oil showed the highest value of yield stress which varies from 10.5 to 15.3 Pa. Lowest yield stress values -2.179 Pa was observed for marble to Electric Discharge Machine (EDM) oil mixture.
d) A uniform plastic viscosity at different time intervals was observed in the paste prepared with water as coolant. In this study a higher value of viscosity 0.444 Pa-sec is observed with cutting fluid paste, and lowest value of viscosity of 0.0027 Pa-sec was observed in the paste prepared with water as coolant.
e) Marble paste prepared exhibits a Non-Newtonian behaviour and it was observed the fluid follows Harshal Buckley Model.

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