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Effects of Binder on Physical and Mechanical Properties on Unglazed Ceramic Tiles

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ABSTRACT

This research mainly focuses on the behavior and functions of different binders and their significant effects on traditional ceramic tiles made by the hydraulic press at 110 bar pressure. Nowadays, the demand for ceramic tiles is increasing, and so their properties should be modified to meet these demands. In that mind, these traditional ceramic tiles were prepared by using various binders. Several tests were carried out for characterization. Moisture contents, firing shrinkage, water absorption, firing weight loss were carried out to check physical properties, and also plasticity test was done for tiles forming capability of raw materials. Besides, modulus of rupture test and impact tests were carried out to check the mechanical properties. Molasses, eggshell, carboxymethyl Cellulose, rice boiling water, flowers were used as a binder in ceramics tiles manufacturing. Each test showed better physical and mechanical properties using carboxymethyl Cellulose.

1. Introduction

Nowadays, the demands of ceramic tiles are increasing. So, researchers show their great interest in working on both floor and wall tiles [1]. Ceramic tiles are used in various sectors like the construction industry because of its attractive color, textures, and design. Therefore, a lucrative and suitable optimized method for the production of ceramic tiles is essential. Several factors of production like utilization of low cost, readily available raw materials like clay, feldspar, quartz, etc. help to produce ceramic tiles with more beneficially. For enhancement of ceramic tiles, different physical properties such as firing shrinkage, density, modulus of rupture act as the quality control factors, which depend on the chemical composition of raw material. On the other hand, the use of locally accessible raw materials for making quality tiles is essential since such a step will strengthen the economic condition of Bangladesh [2]. Organic binder Carboxymethyl cellulose (CMC) and Polyvinyl alcohol (PVA) have been extensively used in making ceramics to enhance the performance. Due to higher strength, water solubility and low price of these binders are the main reasons

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for many centuries [3-4]. In the presence of CMC, the physical and mechanical properties of ceramic tiles are greatly improved. The goal of this study was to evaluate the effects of CMC in clay-based ceramic [5]. For Ceramic tiles production, different methods are used, such as dry press, extrusion, hydraulic press, etc. Because of the simple arrangement, secure handling, a hydraulic press is widely used among them. By using a CMC binder, powder pastes were pressed under pressure in a hydraulic press machine. The formed product means ceramic tiles were allowed to dry and then fired [6-7]. Then the ceramic tiles were tested for density, firing shrinkage, water absorption, modulus of rupture, and impact strength. The objective of this research was to evaluate the physical and mechanical properties of unglazed ceramic tiles. The prospective application of unglazed ceramic tiles may be both in internal& external surface of buildings and in all portion of a house such as floors, ceilings, roofs, fireplaces, walls [8-9].

2. Materials and Method:

2.1 Materials:

The primary raw materials included Ball clay (India), Sherpur Clay (Local), Bijoypur clay (Local), Quartz (India), Feldspar (India), and Burnt brick (Local) and all organic binders were locally imported.

The common raw materials were used for the manufacturing of traditional ceramic tiles, including different types of binders. These were listed below-

Table1. Lists of raw materials used for ceramic tiles manufacturing.

Raw Materials (%wt)	Composition	Binder
Ball Clay (20%)	C-01	Molasses
Sherpur Clay (12%)	C-02	CMC
Bijoypur Clay (10%)	C-03	Egg
Quartz (30%)	C-04	Flower
Feldspar (20%)	C-05	boiled rice water
Burnt brick (8%)		

2.2 Sample Preparation

A hydraulic press machine formed the samples. In this pressing, a stainless-steel mold was used. The sizes of the samples obtained by this method were 40mm×40mm×4mm ((*length*×*width*×*height*) square bars at 110 bar pressure. After forming samples, they must be placed in drying and firing operations such that mechanical and durability could be enhanced. The sample preparation process is shown in Figure 1.

At first, the raw materials were collected according to batch composition. Then the raw materials were weighed, and then water and binder were added and milled in pot mill about 24 hours. The process of ceramic tiles by the hydraulic press is shown below:

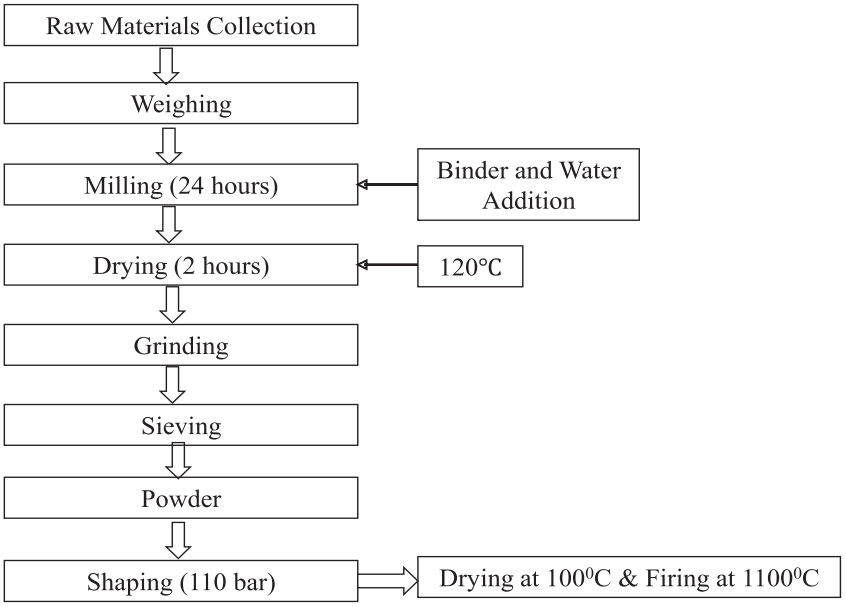

Figure 1. Flow chart of ceramic tiles production.

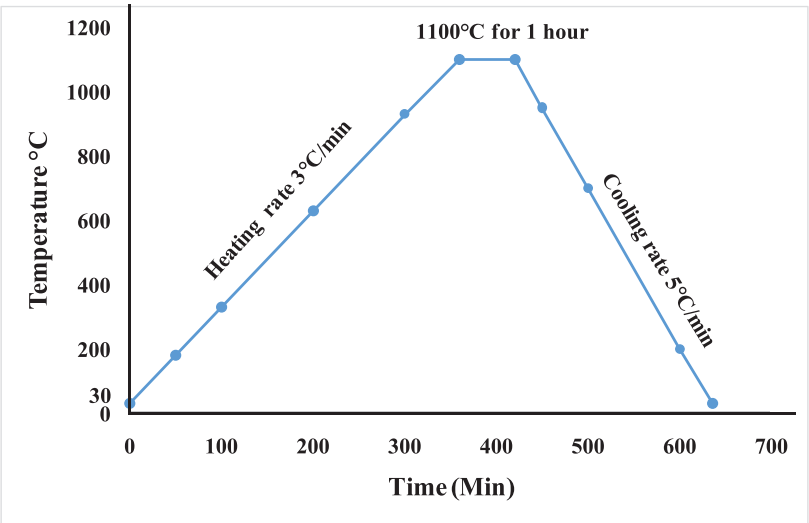

Figure 2. Firing cycle curve for ceramic tiles.

After milling, the slip was collected from pot mill, and then slip was dried at 120 ℃ for 2 hours. After that, the dried powder was ground about 30 minutes with a mortar pestle. Then the ground powder was sieved and poured in the rectangular sample cavity of the hydraulic press machine. The pressing was carried out at 110 bar pressure to make ceramics tiles. After pressing, the pressure was released, and the pressed ceramic tile was collected from the hydraulic press machine. For ease of tiles, removal oil was used. After that, the tiles were dried in an oven (UE600, Memmert, Germany) at 100 ^{0}C for 2 hours and then fired at 1100 ^{0}C for 1 hour. For firing, the initial heating rate was 3^0 C/min. After reaching 1100^{0}C temperature, samples were soaked for 1 hour for better temperature uniformity and then allowed to cool down at 5^{0}C/min inside the furnace. The firing cycle curve is shown in Figure 2.

2.3 Measurement of Plasticity

Plasticity describes the forming capability of a material to the desired shape. Under load conditions, permanent deformation could be occurring, and a new phase will be formed, having different crystal lattices. Good plasticity refers to the properties of a material to permanent deformation without any rising stress or load. The Anderen Pfefferkorn apparatus is used for plasticity based on Pfefferkorn's theory of plasticity. By using the following equation, plasticity can be measured [10]. There is no unit of plasticity because of the same number of ratios.

$$a=h_0/h_f \tag{1}$$

Where, h_0= initial height, h_0= final height

2.4 Measurement of Moisture content and Firing Weight Loss

The Moisture content is an important concern of a material as it varies among such factors like shipping, storage, chemical and physical nature of the material. Water may result in the materials in two ways, such as mechanically and constitutionally. The mechanically held moisture content is determined by calculating the difference between dried and wet samples [8]. In this way, the weight loss after drying and firing samples also determined. It can be given on a volumetric or mass basis.

Moisture content and Weight loss of sample

$$\% \, w = (w_1-w_2)/w_1\times 100\% \qquad \%wt \tag{2}$$

Where, w_1= weight of the wet sample, w_2= weight of the dry sample

2.5 Measurement of Firing Shrinkage

A hydraulic press made three square bar shape (40mm×40mm×4mm) ceramic tiles. The pressed tiles were then dried at 100^0C for 2 hours. The dried tiles were then fired at 1100^0C for 1 hour. The following equation then calculated the firing shrinkage [8]:

$$\% \text{ Firing shrinkage} = (\text{Dry length}-\text{Fired length})/(\text{Dry length})\times 100\% \tag{3}$$

2.6 Measurement of water absorption

Water absorption is one of the significant concerning properties of ceramic tiles. Water absorption is measured by the boiling point method. This test is carried out to measure the amount of water absorbed under the boiling environment for 24 hours. Factors that affect water absorption are a type of plastic, binder type, temperature, etc.

Water absorption % by mass is measured by following equation [8, 10]

$$\% \text{ of water absorption} = (w_2-w_1)/w_1\times 100\% \qquad \% \text{ wt} \tag{4}$$

Where, w_1= weight after firing, w_2 = weight after absorbing water

2.7 Measurement of Density

The properties, density plays a vital role in ceramic tile. Density is defined as the measure of mass per unit volume of the sample. It is determined by the following formula [8]:

$$d=W_a/W_c-W_a\times D \qquad g.cm^{-3} \tag{5}$$

Where d= density of test sample, W_a = weight of dry test sample W_c= weight of test sample soaked and suspended in air, D = density of the immersed liquid at the testing temperature

2.8 Measurement of Modulus of Rupture

Modulus of Rupture (MOR) is also an essential property of ceramic tiles. It determines the bonding strength of the test samples. It also represents the maximum stress that can be tolerated by these test samples. A three-point bending machine measured it. Modulus of rupture is measured by the following equation [8, 11]:

$$\text{Modulus of rupture, } \sigma = 3FL/2bd^2 \quad \text{MPa} \tag{6}$$

Where, F = Load on sample, L = length of sample, b = Width, d = Thickness

2.9 Measurement of Impact Strength

When a sudden load is applied to a sample, the sample can be a fracture or not. Impact strength is the ability of a material to withstand a suddenly applied load. Both the Izod and Charpy Impact Test measure it. The impact test was carried out by the Charpy machine to measure the impact energy required to fracture of the test samples. Therefore, the impact strength is expressed in terms of energy.

3. Results & Discussion:

3.1 Plasticity:

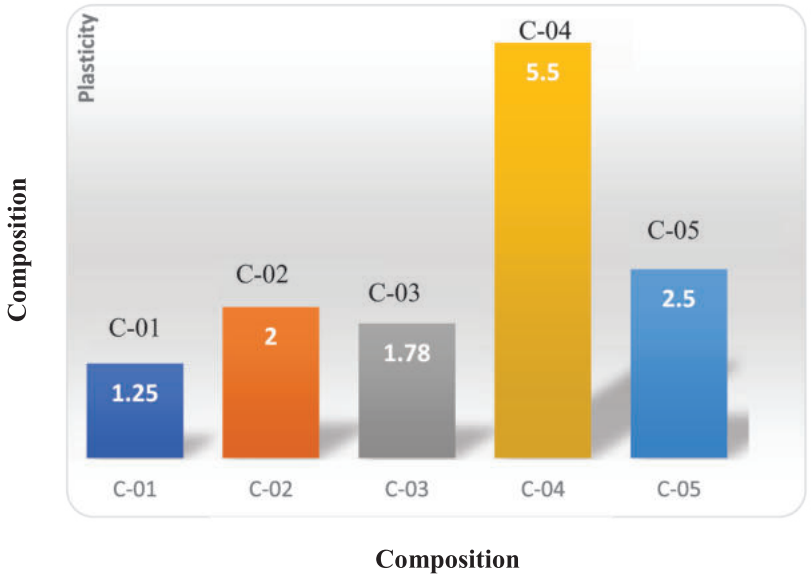

Figure 3. Plasticity of different ceramic tiles .

Ball clay and Sherpur clay has the highest plasticity. For the plasticity test, 40mm×33mm (height×diameter) three cylindrical samples for each binder was used. Pfefferkorn plasticity sample maker made this sample. Pfefferkorn theory was used to evaluate the plastic index of ceramic tiles. This figure shows that good plasticity is achieved using carboxymethyl cellulose as a binder in tiles formation. CMC binder increases the viscosity of samples because of molecular interaction and the formation of a sizeable tridimensional chemical bond. The plasticity is also suitable for boiled rice water due to its excellent binding properties.

In contrast, the highest plasticity was achieved by using flowers. But it was not good because it contains moisture and also decreasing the viscosity due to its oily. Therefore, the capability of sample making was too weak. Molasses and eggs also reduced the plasticity of tiles mean too hard.

3.2 Moisture Content:

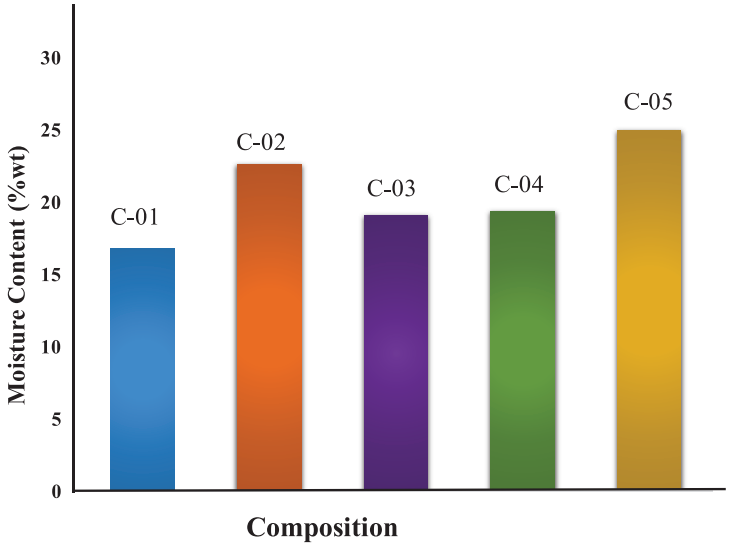

Figure 4. Moisture contents of different ceramic tiles .

Moisture contents of various ceramic tiles are shown in figure 4. Three square bar shape (40mm×40mm×4mm) samples for each binder were used for moisture content test. It shows that the tiles using CMC and boiled rice water binder contains more moisture content due to their high mechanical bonded water and also for chemical and molecular bonded water. The other tiles contain lower moisture because of their lower chemical and molecular bonded water.

3.3 Firing Weight Loss:

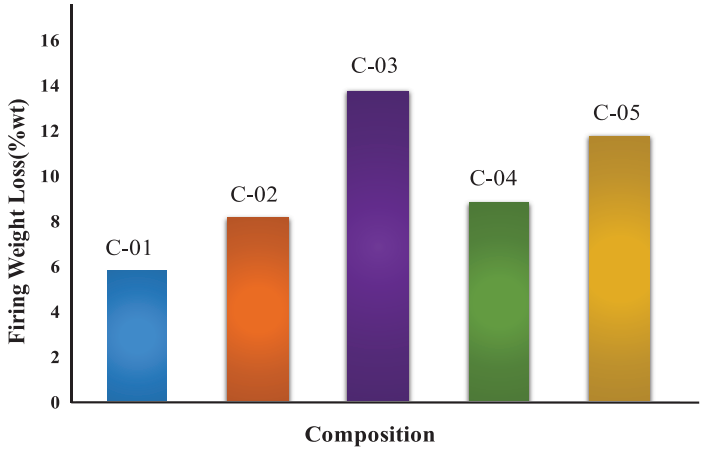

Figure 5. Firing weight loss of different ceramic tiles .

Three square bar shape (40mm×40mm×4mm) samples for each binder were used for firing weight loss. Firing weight loss is a fundamental property of ceramic tiles because after losing the final weighted tiles were found. The firing weight losses of different ceramic tiles are shown in figure 5. The tiles (containing the egg binder) exhibit more firing

weight loss because of releasing of a high amount of moisture content during firing. Due to releasing of moisture, the CMC binder tiles weight loss was moderate after firing except tiles that contain molasses binder.

3.4 Firing shrinkage:

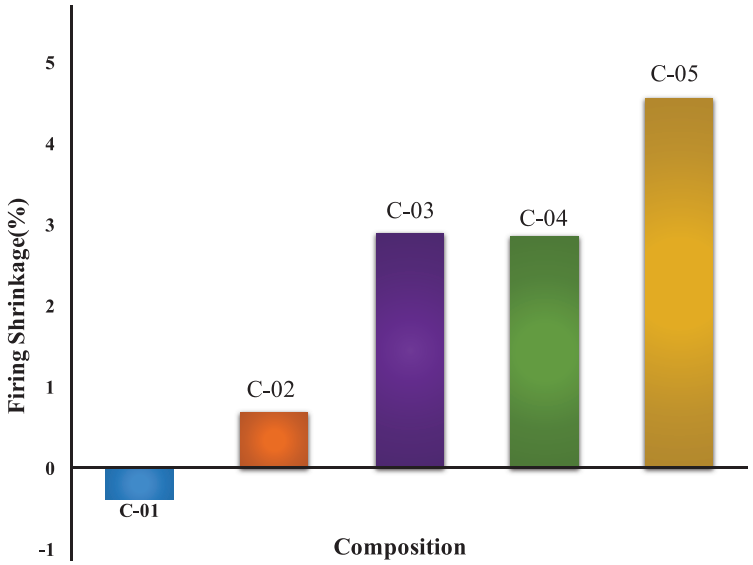

Figure 6. Firing shrinkage of different ceramic tiles .

The firing shrinkage of different ceramic tiles is shown in figure 6. From the figure, it shows that the ceramic tiles using molasses binder is expand due to mismatch of binder and burnt brick. But using CMC, the ceramic tile is compacted so much, and so little shrinkage occurs, and density increases. On the other hand, tiles formed by using egg, flower, rice boiled water binder contains more moisture, and for that, the tiles are shrinking more because of releasing moisture from the tile's body.

3.5 Density:

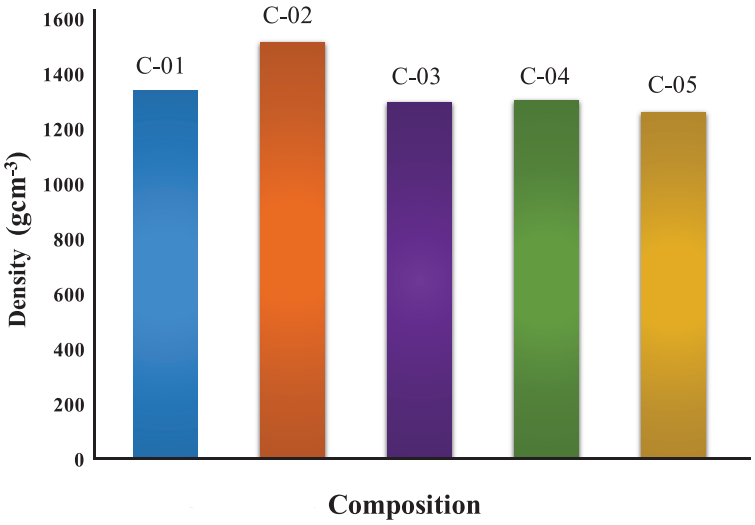

Figure 7. The density of different ceramic tiles .

The density of different ceramic tile was tested and plotted, which is shown in figure 7. It shows that the tiles formed by using the CMC binder have the highest density due to releasing moisture content, and the particles get close to one another, and so more compaction occurs. The highest density is also one of the significant required properties of ceramic tile. Other tiles are also having a good density (figure7), but lower than the CMC binder because of its slightly lower compaction.

3.6 Water Absorption:

After firing the ceramic tile sample, a water absorption test was carried out. This test was performed at boiling temperature for 24 hours. Three square bar shape (40mm×40mm×4mm) samples for each binder were used for the water absorption test.

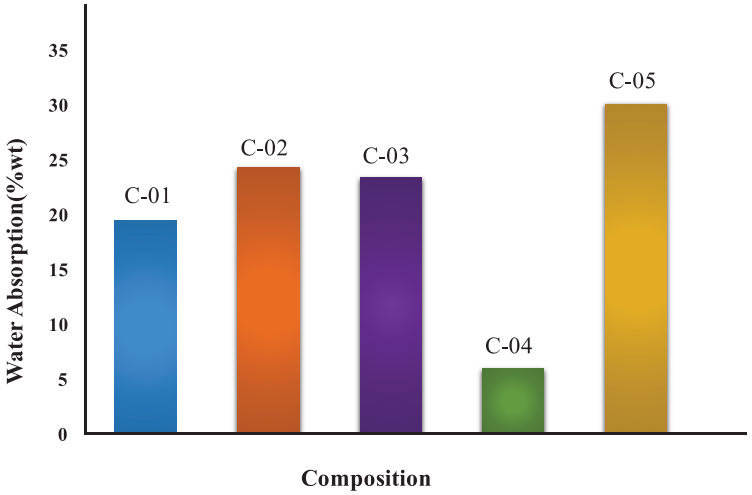

Figure 8. Water absorption of different ceramic tiles.

The water absorption of different ceramic tiles is shown in figure 8. It can be concluded that the water absorption of these tiles is lower due to the oily nature of the flower as a binder. And the other tiles formed by using different binders such as egg, CMC, boiled rice water, and molasses absorb slightly much water because they are not so oily.

3.7Modulus of Rupture Test:

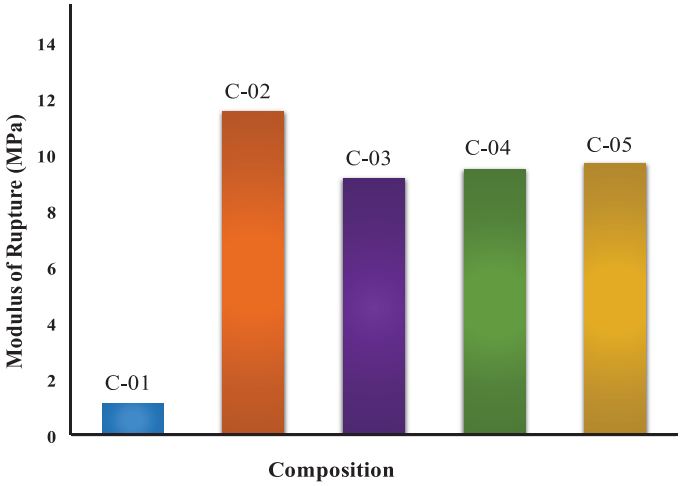

Figure 9. Modulus of rupture test for different ceramic tiles.

A three-point bending machine was used for this test. Three square bar shape (40mm×40mm×4mm) samples for each binder were used for Modulus of rupture (MOR) test. By measuring MOR value, the service life of ceramic tiles can be predicted. Figure 9. shows that the tiles contain a CMC binder, have the highest MOR value because of having excellent bonding properties of binder and also for containing a high amount of alumina in the tile's body. This type of ceramic tiles was beneficial for floor covering and building materials [9]. Besides the tiles using egg, flower, boiled rice water has almost the same MOR value because of the feldspar and ball clay amount but a little variation due to bonding. But the tiles using molasses binder shows the lowest MOR value among others binder because of mismatching of bonding with the raw materials.

3.8 Impact Test:

When tiles are in an application, a sudden load may impact on the tiles. Especially on the floor covering application, the probability of acting sudden load on tiles is high [9]. So, impact resistance is an essential property of ceramic tiles. Three square bar shape (40mm×40mm×4mm) samples for each binder were also used for impact test. The impact resistance of different ceramic tiles is shown in figure 10.

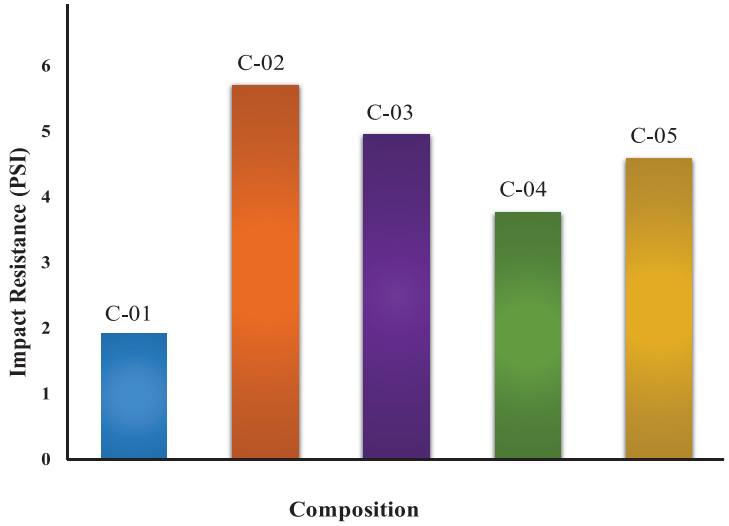

Figure 10. Impact resistance of different ceramic tiles .

From that figure, it can be said that the impact resistance of tiles using CMC binders has a higher value than others due to its high compactness and density, and it is possible only due to the excellent binding properties of CMC. The impact resistance value is lower for molasses binder because of its low compactness.

Conclusion

Carboxymethyl cellulose is an excellent binder, indeed. All of these properties of ceramic tiles using CMC were good because of their excellent binding behavior. From this research, it can be suggested that using two or more binders together in ceramic tiles formation. The properties also may be more useful for different applications all over the world.

Acknowledgments

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