

Investigating the effect of eggshell burning temperature on the mechanical properties of artificial teeth

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Abstract. In the field of health, ceramics are used for the repair, reconstruction and replacement of the teeth and bones and the body tissue, which is now very possible to be developed into bio-ceramics. Bio-ceramic materials can be used for the manufacture of artificial teeth, wherein this material consists of kaolin, quartz, feldspar, and eggshell. The use of eggshells as an added ingredient and reinforcement in the artificial teeth has been studied and reviewed in some literatures, but they report the effect of temperature on the burning of egg shells is still lacking. This paper investigates the effect of eggshell burning temperature on the mechanical properties of artificial teeth. The effect of different burning temperatures on hardness is also presented.

1. Introduction

Materials of artificial teeth are generally imported and expensive. Utilizing natural ingredients as denture materials is expected to reduce the cost of manufacture. Natural ingredients for artificial teeth are widely available in Indonesia and spread in various regions. Artificial teeth with ceramic materials based on porcelain consist of feldspar, quartz, and kaolin. This artificial tooth has several advantages, i.e. the higher mechanical properties, the color can be adjusted with the original teeth, and have good biocompatibility [1].

Feldspar was a natural mineral containing potassium, alumina and silica. Feldspar obtained from the crushed rock [2]. Quartz stone was a mineral crystal stone made of silicon dioxide. This mineral material has a hexagonal crystal structure [3]. Kaolin is a mineral found in sedimentary rocks known as claystone [4]. The following is a standard chemical composition of porcelain materials on some dental ceramic applications [5].

Table 1. Chemical composition of the dental porcelain [6].

| | Composition (%) | | | | |
|------------------|------------------|--------------------------------|------|-------------------|------------------|
| | SiO ₂ | Al ₂ O ₃ | CaO | Na ₂ O | K ₂ O |
| Dentin | 66.5 | 13.5 | - | 4.2 | 7.1 |
| Email | 64.7 | 13.9 | 1.7 | 7.5 | 7.3 |
| Dental Porcelain | 62.2 | 18.7 | 14.7 | - | 12.2 |



The egg shell is one of the potential ingredients of bio-ceramic material and very easy to find in Indonesia. The egg shell has the highest concentration of CaCO_3 (Calcium Carbonate), it can be reach to 95%. This we have proved by testing the duck eggshell composition by using the Quant'x EDXRF Analyzer at the Physics Laboratory of Hasanuddin University. The results of analyzer was shown that the duck eggshell have the composition of CaO about 99.41%.

Utilization of the egg shell waste can be converting into a hydroxyapatite powder. Hydroxyapatite was a term used to describe a bond containing calcium ions that can be combined with orthophosphates, pyrophosphates, hydrogen, or hydroxides which are the main ingredients in bone formation and tooth enamel, so-called biomaterials [7].

The eggshell serves as a protective barrier against the penetration of microorganisms [8-9]. Shell is a bio-ceramic composite material with an extracellular assembly structure, which serves to protect the contents of the egg and to ensure the calcium needed for the formation of the chick's skeleton. The egg shell has several porous layers, which penetrate water and gas, allowing the embryo to breathe [10].

The egg shell is divided into several protein fiber tissues, associated with calcium carbonate crystals (96% by weight of shell), magnesium carbonate (1%) and calcium phosphate (1%), as well as organic and water. Calcium carbonate (CaCO_3), the main composition of the shell, is a naturally occurring amorphous crystal in the form of calcite (hexagonal crystals), with low water solubility (13 mg/L, at 18 °C) [10-11].

The egg shell contains two internal membranes, composed of a mixture of proteins and glycoproteins, which are closely related to the shell, except at one end where they separate to form an air space [10]. The chicken egg shell, a calcium-rich bio-ceramic composite, offers a unique combination of particle strength, reactivity and cost, capable of absorbing acidic gases such as carbon dioxide [12]. Egg shells containing Calcium Carbonate (CaCO_3) powder can act as agents in removing heavy metals from water and soil. Liao et al [13] and De Paula et al. [14] have shown that derivatives from egg shell waste can be used effectively to remove some divalent metal ions, such as lead, cadmium and copper, from aqueous solutions. Ok et al [15] concluded that the utilization of egg shell waste as an alternative to CaCO_3 for immobilization of heavy metals in the soil. In accordance with Yoo et al [16], Egg shells containing CaCO_3 can be used in paper treatment as a substitute for minerals, to increase brightness, opacity and strength. CaCO_3 can also be used to improve paper appearance and texture, as well as performance in relation to multicolor printing.

The other utilize of egg shells is as a solid catalyst in the transesterification of vegetable oils with methanol to generate biodiesel. Wei et al [17] achieved highly active solid catalysts that can be reused only through the calcination of egg shells. Reuse of eggshell waste is proposed for preparing such catalysts and simultaneously to minimize waste from valuable shell scraps, so that cheaper catalysts can be developed. Biodiesel production process is more economical and environmentally friendly in the presence of eggshell catalyst is very cheap and efficient, so it can reduce the cost of biodiesel and make it competitive with diesel oil. The content of eggshell membranes are valuable biomaterials such as collagen, polypeptide and amino acids, which are very useful for cosmetic and medical applications [16].

2. Recent finding on mechanical properties

Rauf N (2017) has conducted a study on the effect of eggshell addition on porcelain-based denture's physical properties, ie chemical composition, density, hardness and shrinkage. The results showed that porcelain dental with the eggshell has better physical properties than without eggshell. In the composition of 1: 1: 1: 1, the content of CaO has a high content of 56.87%, silica (SiO_2) 39.50%, Al_2O_3 3.04% and no containing Fe_2O_3 [18].

The content of oxide on the original tooth is CaO 61.60% and P_2O_5 38.34%. The original teeth do not contain Al_2O_3 and SiO_2 , but if there is very small because the teeth grow as the human age increases. Al_2O_3 and SiO_2 serves as a binder, forming and adding strength from ceramics. The value

of density and burn reduction will be increase with the burning temperature of 800oC - 1000oC on the dental sample [18].

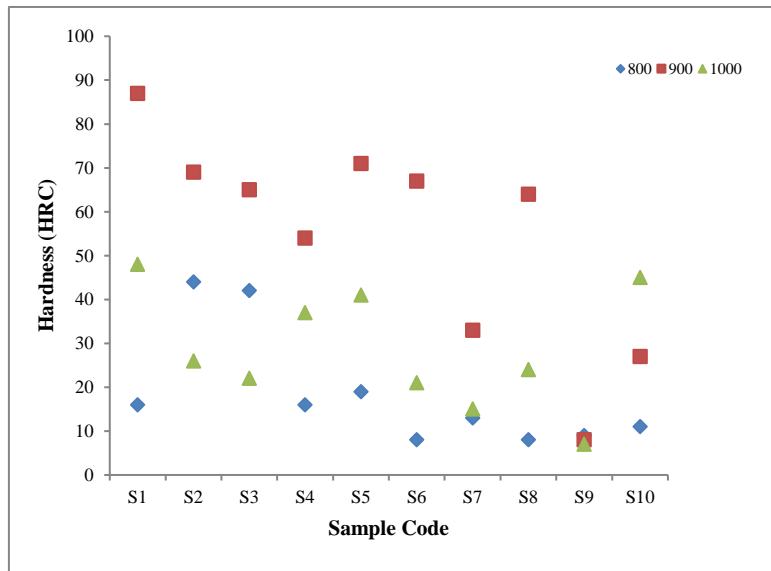


Figure 1. Result of hardness for some samples [18].

The composition of each sample for a total mass of 6 grams is shown in the following table:

Table 2. Chemical composition of the dental porcelain [18].

| Code | Feldspar | Quartz | Kaolin | Eggshell |
|------|----------|--------|--------|----------|
| S1 | 1.5 | 1.5 | 1.5 | 1.5 |
| S2 | 1 | 2 | 2 | 1 |
| S3 | 0.86 | 2.57 | 1.71 | 0.86 |
| S4 | 0.75 | 2.25 | 2.25 | 0.75 |
| S5 | 0.67 | 2.66 | 2.00 | 0.67 |
| S6 | 2 | 2 | 2 | - |
| S7 | 3 | 1.5 | 1.5 | - |
| S8 | 2.4 | 2.4 | 1.2 | - |
| S9 | 2 | 2 | 1 | 1 |
| S10 | 2.4 | 1.2 | 1.2 | 1.2 |

Table 2 shows varying hardness values. These results indicate that the hardness values in eggshell samples (S1, S10) were higher than those without eggshell (S6, S8). The hardness value will increase in temperature 900oC and decrease at 1000oC for both type of samples (with and without egg shell). Decreased hardness can be caused by a fracture in the sample during combustion to a temperature of 1000oC.

The sample hardness is strongly influenced by its mineral content. Samples with high CaO have high hardness values as well. Burning the sample at a temperature of 900oC – 1000oC will occur crystallization process. In the process of crystallization, the calcium bond is weakened and easily broken so that the value of violence is reduced. Table 2 shows that the sample hardness of S2, S3, S6 and S8 is close to the hardness value of the teeth (68 kg/mm²) at 900oC.

Other experimental of Sitorus et al. [19] were conducted the burning dental materials based on porcelain materials. The combustion temperature used is 800 – 1000oC. These burning results occurs

the burn reduction. Burn reduction is the process of depreciation of goods made from soil that has dried up after being burned. During the combustion process, all residual water will evaporate and be accompanied by loss of the binder. The amount of burn reduction for dental is <40% [20]. Burn reduction (BR) of dental porcelain can be determined by using the equation as below [18]:

$$BR = \frac{\text{dry volume} - \text{volume after burn}}{\text{dry volume}} \times 100\% \quad (1)$$

The result of measuring the burn reduction can be shown as figure below.

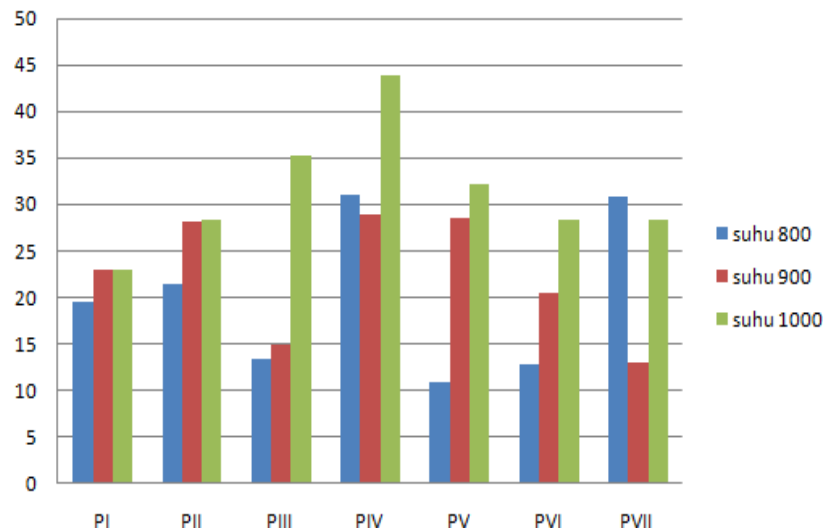


Figure 2. Diagram of burn reduction [19].

In figure 2, it is clear that the burn reduction recommended is less than 30% at 900 ° C. It can be occurred the sintering process at temperatures between 800 – 900°C. Basically, the sintering is the process to remove the pores of materials, occurred the shrinkage of components at the same time, and followed by increased bonds between adjacent particles, resulting in a compact material.

Reconstructive transformation occurs at a temperature of 867°C from a hexagonal structure to a crystalline trydimite, resulting in a shrinking sample of no more than 30%. While the reduction is greater at a temperature of 1000 ° C, but do not know the structure formation exactly. The results of experiment obtained the hardness values as following below.

Table 3. Result of hardness [19].

| Sample Code | Hardness | | |
|-------------|-------------|-------------|--------------|
| | 800°C (HRH) | 900°C (HRE) | 1000°C (HRD) |
| PI | 93 | 93.7 | 98 |
| PII | 99 | 99 | 99 |
| PIII | 63.7 | 98 | 99.7 |
| PIV | 47.7 | 55.3 | 72 |
| PV | 99 | 91 | 97.7 |
| PVI | 96 | 97.7 | 96 |
| PVII | 98.3 | 95.7 | 98.7 |

The burning temperature of 800°C is the lowest scale, the hardness value is very low and can only be measured on the penetrator 1/8 "Ball and the load of 60 kg. The sample of 900°C can be measured on the same penetrator but the load is 100 kg. For the temperature of 1000°C, penetrator used is Diamond with a load of 100 kg.

The bio-mimetic method would suggest similar properties of resin composites such as stiffness and strength compared to the replaced tissue, i.e. mostly dentin, for which the modulus and strength were located in the range of 20 – 25 GPa (Young's modulus) and 52 – 105 MPa (ultimate tensile strength) [14].

The mechanical properties of dental resin-based composites (RBCs) are strongly influenced by filler characteristics (size, content, geometry, composition). Amongst the modern red blood cells occur changes the mechanical properties and filler characteristics vary significantly [15].

3. Concluding remarks

The egg shell waste from chicken/duck egg processing plants can be reutilized as a source of raw materials for industries. This investigation highlighted the using eggshell for dental composition, and effect of burn temperature on mechanical properties. The reutilized of egg shell components can reduce risk of microbiological problems and the costs of disposal into the environment as well as supply raw materials to displace CaCO₃ obtained from non-renewable sources and production of other by-products. This paper proposes alternative uses for several components of egg shells.

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