Physical Properties Characterization of Ceramic Waste Particles Used as Filler in Boat Hull Production: A Proposed Study

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Abstract. Various types of composite materials were being used in boat manufacturing especially for hull production as a main part. Natural composite materials such as teak sawdust, wood ash and silica particles have been utilized in boat hull making from previous researchers. This paper revised mechanical properties impact on several composite materials mixed with epoxy resin matrix by using hand lay-up method. Other than that, the main focused in this study is on the application of ceramic particles waste as a composite material. In-stead of being used as land-filling, ceramic particles waste can be reused in becoming value-added composite materials in specific area which brings benefits to environment and enhance the properties for other materials in terms of physical and mechanical. This study also presents an assembled and up-to-date review of physical, mechanical, durability and other durable potential abilities of ceramic fine aggregate which have huge ability usage in concrete production, soil stabilization, bricks block and road pavement structure. The percentage of particles usage from previous studies were from 2% up to 20% and the findings indicate that usage of ceramic waste particles improves flexural, durability, compressive, geotechnical and mechanical strength properties compare to standard materials usage. Thus, a new application area will be explored from this study on the usage of ceramic particles waste to the resin on the interface between the composite materials and core materials used in production of boat hull.

Keywords: Ceramic Waste Aggregate · Boat Manufacturing · Composite · Mechanical Strength · Boat Hull

1 Introduction

A composite material is a combination of two or more materials that exhibits superior qualities than those of the component parts utilized separately. A reinforcement and a matrix are the two constituents [1].

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We can find a matrix-based classification such as the classification through the many composite material classification schemes, where the important types of advanced composites can be depicted in the pie chart below Fig. 1, which describes the five principal types of advanced composite material in wide use. Polymer Matrix Composites (PMC), Metal Matrix Composites (MMC), Ceramic Matrix Composites (CMC), Carbon-Carbon (CC), and Hybrids comprised of a combination of the aforementioned matrices are among the composite varieties [2].

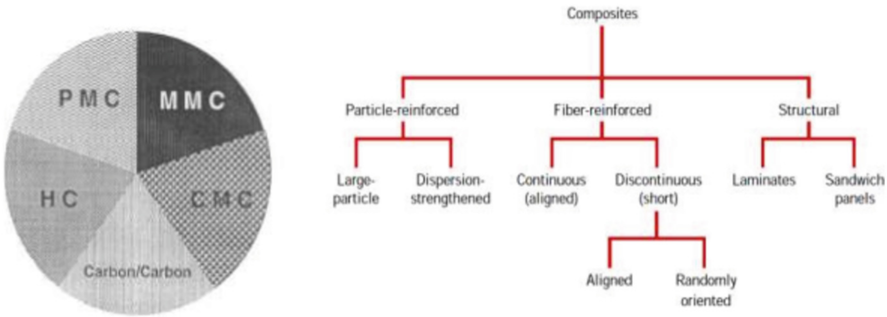

Fig. 1. Composite reinforcement flow [2].

The field of composite materials science is rich and full of design varieties and potentials. In depth study is needed in order to understand the relevant design aspects, methodology and tools of composites; because they differ greatly from those for standard building materials such as steel and aluminum.

The aim of this study is the assessment of the filler properties used within PVC foam for boat hull production using waste ceramic waste particles as natural fine aggregate partial substitute for structural adhesive bond. In order to achieve this, waste ceramic particles were mix in several percentage ratio to test the mechanical properties from the mixing samples.

2 Composite for Boat Hull Production

Composites will play a growing role in boat building due to their lightness, strength, durability, and ease of production. Nonetheless, composites are just recently becoming a key material of choice in some industries. The use of composites in the construction industry is steadily expanding. Fiber reinforced polymer (FRP) composites are widely used for fortifying boat hull because they have many advantages over conventional strengthening methods [3]. Carbon, glass, and aramid fibres are commonly employed in the manufacture of FRP composites for construction. All of these fibres are commercially accessible as continuous filaments. To bind the fibres together, the polymer resin surrounds and encapsulates them, safeguard them from adverse effects, sustain their proper position, and facilitate the division of load between them.

2.1 Natural Composite for Boat Hull Production

Historically, the vast bulk of the maritime sector has relied on various recreational or pleasure boats of various sizes, generally made of conventional composites. Furthermore, the shipbuilding industry has been seeking for many years to include more composite materials in major merchant and passenger ships via hybrid hull designs [4]. Some uses include a composite bow and stern structure, a composite outer layer that is supported by a steel truss, straightforward integration of composite load-carrying decks within a traditional steel ship structure, and even a complete ship hull composed of composite material.

The economics of bio-composites, mechanical properties of different types of bio-composites in standard and marine environments, fouling resistance, and the effects of hygroscopicity, biodegradability, and eutrophication on structural integrity and the marine environment are all addressed in research and development of bio-composites. Study presented by [5] for the usage of epoxy resin mix together for ship hull components studied on tensile and flexural durability with 28 m% bio-based carbon content supplemented with flax and hemp (dry and wet). The results of tensile were 68.6 MPa and 73.8 MPa for dry and wet flax, 73.8 MPa and 39.1 MPa results for flexural test for dry and wet flax. Meanwhile, for tensile test of dry and wet hemp were 45.7 MPa and 31.3 MPa, flexural test resulted in 81.2 MPa and 60.4 MPa for dry and wet hemp. It shows that flax and hemp have different strength in tensile and flexural test. Dry flax has the highest tensile strength for overall results and wet hemp has higher flexural strength compare with dry hemp.

Usage of Ceramic Waste for Improvement in Various Areas. It is believed that around 30% of the daily manufacturing of ceramic tiles goes into waste, which waste will not be recycled in any way at this time [6]. However, Ceramic waste was long-lasting, robust, and resistant to biological, chemical, and physical degrading processes [7]. As the ceramic tiles piled up every day, the ceramic industries were under pressure to find a solution for this form of disposal. Meanwhile, conventional stone crushed aggregate reserves are rapidly dwindling; however, the effective use of inorganic industrial leftover products will result in a more sustainable and environmentally friendly environment [8].

Recyclables ceramic tiles are far too impure to be re-used in tile production and are typically disposed of as junk in landfills. The elimination of ceramic tiles in the surroundings causes problems due to the vast amount of waste produced every single day, which may increase the cost of management. If this waste becomes a burden on the ceramic industries to adopt a feasible solution for this type of disposal, it would have a negative influence on the environment. Unfortunately, the removal of waste ceramic tiles will add an additional maintenance cost to the total production costs [9]. Using this waste for other purposes is one solution to this challenge [10]. Thus, waste ceramic tiles can be recycled in order to save money and introduced as new materials from waste to wealth [11].

Several research have been conducted on the application of ceramic waste as coarse particles, powder, and filler in cement mortar preparation [12–14], concrete [15–17] and self-compacting concretes [18–20], high strength concrete [21] and ultra-high performance concrete [22]. Researchers have also researched and analyzed the mechanical properties of mortar and concrete containing ceramic waste. The majority of data demonstrated that the mechanical strength of concrete is comparable or even better than those containing natural aggregates for up to optimal percentage substitution of natural sand by ceramic waste. The influence of ceramic waste as aggregate (CW), dust (FTDA), and their combinations on the production of concrete was investigated. They discovered an increase in compressive and flexural strength of around 13.53, 16.70, 2.91% and 23.21, 0.10, 19.47% at 2, 7, and 28 days [7].

Aside from that, ceramic tile waste is used for road slope embankment. Study was done by [23], evaluated the utility of ceramic tile waste (CTW) as an admixture for fine sand, with a focus on increasing the engineering qualities of fine sand to make it capable of reducing cross section of embankment for roadway construction. Results shows that when CTW were used up to 12%, may also increase the height of embankment and at the same time reduce the cost of working materials which varies from 16% to 20% cost of reduction. It shows that the properties of the CTW which is high durability and strength can be used for another replacement in various field of area.

Study done by [24] related with percentage of ceramic particles used in boat hulls production to accelerate aging test and also mechanical test using 2% of nano-silica which is from the ceramic waste particles. Results from this study shows that the addition of 2 wt% nano-silica permitted to increase the material flexural strength in 5.8%. The study also reported for 1000h aged configuration and sample with additional of 2% nano-silica resulted in increased flexural strength up to 8.7%. Silicon painting was applied in order to protect the hull from corrosive environment.

Study done by [25] related with the utilization of ceramic tile demolition waste (CTDW) as a paste were used up to 30% of CTDW comparing with limestone as a reference filler in Portland cement. The results show better increment up to 5% for CTDW comparing with limestone. Throughout this study, the material preparation of CTDW were being follow up as a reference. CTDW powder was processed for 1 h at 300 rpm in a planetary ball mill, yielding a diameter of 76.5 μm.

3 Material and Methodology

Multiple processes are required, beginning with the processing of the ceramic particles from raw sizing into smaller particle sizes via milling. Then, the particles will undergo meshing process using mechanical sieve shaker to segregate the size of ceramic particles before being compared with existing composite industrial filler, which are KONASIL K200 and Q-Cell 5020. The finest ceramic particles from sieving process will be test through the Particle Size Analyzer (PSA) to analyze the peak size of the particles and also undergo morphology to investigate quantified information physical relationship of the size of ceramic particles and existing composite industrial filler. Table 1 shows the properties and application of industrial filler used for production of hull.

Table 1. Properties of industrial filler used for hull production.

	KONASIL K200	**Q-CEL 5020**
PROPERTIES	• Fluffy, white powder of nano-sized amorphous structure • Extremely small particle size and spherical, morphology, high surface area, unique surface chemistry and high purity	• Single cell hollow microspheres appear as a white free flowing powder • As filler to reduce density but can enhance other properties as well
CHEMICAL COMPOSITION	• $SiO_2 > 99.8\%$ min • $Al_2O_3 < 0.05\%$ max • $Fe_2O_3 < 0.003\%$ max • $TiO_2 < 0.003\%$ max	• $SiO_2 + B_2O_3 > 99.5\%$ min • Siloxane $< 0.5\%$ max • Methyl Hydrogen $< 0.5\%$ max
PARTICLE SIZE	7 µm to 40 µm	30 µm -125µm

3.1 Milling Process

Preparation of the ceramic particles by undergo laboratory mill using Retsch Planetary Ball Mill PM-100 by using several milling speeds in Table 2. The purpose of having milling process is to verify the particles distribution and obtained specific sizes of ceramic particles up to micrometer sizing.

Table 2. Milling Parameter Ball Mill PM-100.

Milling speed (RPM)	**Milling time per cycle (min)**	**Jar sizes**	**Milling ball types**	**Milling ball charge (piece)**
300	30	250ml	Stainless Steel Grinding Balls	7
350	30			
380	30			

Particle Size. The cone and quartering technique were applied to get the necessary sample for the analysis of ceramic particles following crush, then optimum sieving time, 30 min per cycle to get particle size distributions, it was determined for all samples. For dry sieving testing, a Ro-Tap shaker (Retsch GmbH, Haan, Germany) was utilised (with an amplitude of 50 on a 0–100 scale and a constant vibration frequency of continuous). Apertures on laboratory wire mesh sieves were 425 m, 250 m, 150 m, 63 m, and 32 m. Related with sieving rate, the after milling particles where weight for 50g to be sieved for 30 min. This is because the water absorption for ceramic particles were 4% to 6% when exposed to the surrounding making the particles agglomerate and clumped when the quantity is overload.

Particle Size Analyzer (PSA) Anton Paar 1190 multi-laser system with measurement range liquid of 0.04 m to 2500 m and dry range of 0.1 µm to 2500 µm was used to analyse the distribution of ceramic particles after sieving procedure. In order to obtain the average distribution pattern for each powder, all sieving samples powder with milling ranges of 300 RPM, 350 RPM, 380 RPM, and existing industrial filler were examined. The particle size distribution and zeta potential of the samples were determined. Dynamic light scattering (DLS) studies with the Litesizer 500 in were used to accomplish laser diffraction measurements. Surfactant must be applied before running to avoid powder agglomeration when the samples are inserted into the PSA medium. Surfactants are amphiphilic molecules that support particle dispersion by reducing surface tension between particles and the surrounding medium. Thus, for ceramic particles 4% of Calgon solution (sodium metaphosphate) were applied to the PSA medium shown in Table 3.

Table 3. PSA setting parameter.

Surfactant media	Ultrasound	Stirrer speed	Pump speed	Measuring time
4% Calgon Solution	During measurement	Medium	Medium	30 s

The morphology of each filler was examined using a JEOL JSM SEM-6360 Scanning Electron Microscope (SEM). Fillers were placed in a graphite die with an external and internal diameter of 30 mm and 15.5 mm, respectively, as well as a graphite punch with a diameter of 15 mm and a height of 20 mm. Subsequently, the powders coated using Aurum (Au) by Auto-Fine coater model JEOL JFC-1600 (Fig. 3.6b) for 5 to 10 min for each sample under an applied pressure of 5 Pa and carried out in a vacuum.

4 Results

4.1 Particle Size Distribution

The screening of ceramic waste particles after milling reveals that a speed of 380 RPM produces the closest mean size to industrial filler, which is in the range of 15 μm to 16 μm as shown in Fig. 2. It shows that ceramic waste particles able to achieve nearest particles size towards the industrial filler (KONASIL K200 and Q-CEL 5020) whereas the highest percentage of materials content in the ceramic waste particles were silica (SiO_2) content which is in the range of 70% to 75%. Thus, this material is suitable to be formulated as filler content in PVC foam for the hull production.

Apparent Density. Perceived density is affected by moisture content, solid type, and air volume percentage. The apparent density of ceramic waste particles was in the range of 0.542 to 0.55 g/cm^3 which is higher than industrial filler as shown in Table 4. Results shows that ceramic waste apparent density higher than industrial filler. Thus, it will slightly affect the weight volume applied on the PVC core in hull production.

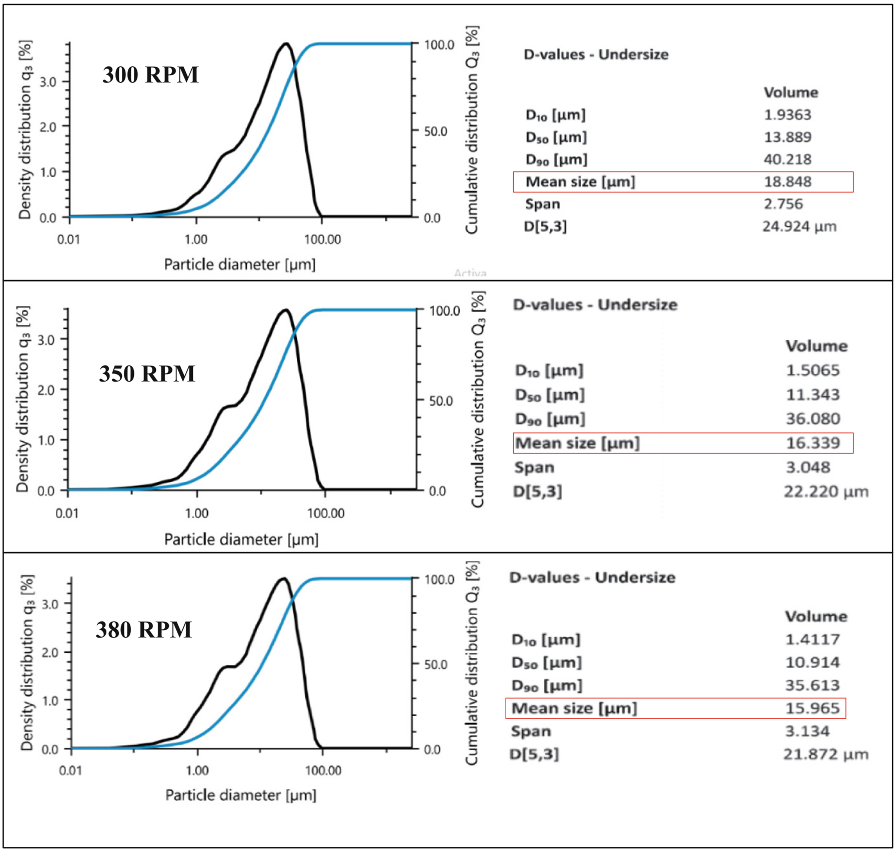

Fig. 2. Mean size after milling for ceramic waste particles.

Table 4. Apparent density of industrial filler and ceramic waste particles.

Fillers Type	**KONASIL K200**	**Q-CEL 5020**	**CERAMIC WASTE PARICLES**
Apparent Density (g/cm^3)	0.212 – 0.2	0.14 – 0.2	0.542 – 0.55

Through this comparison, the mixing formulation for the filler must be considered by this apparent density as it will affect the overall volume and density of the hull production. By the properties presented by industrial filler, it shows that industrial filler has lower Elastic Modulus (E), Hardness (HR) and Tensile Strength (σ) comparing to ceramic waste particles. These properties are related with the apparent density of the materials.

Apparent Density. *Specimen Morphology.* Zoom magnifications of 150x and 400x, the microstructures of KONASIL K200, Q-CEL 5020, and ceramic waste particles are shown in Fig. 3.

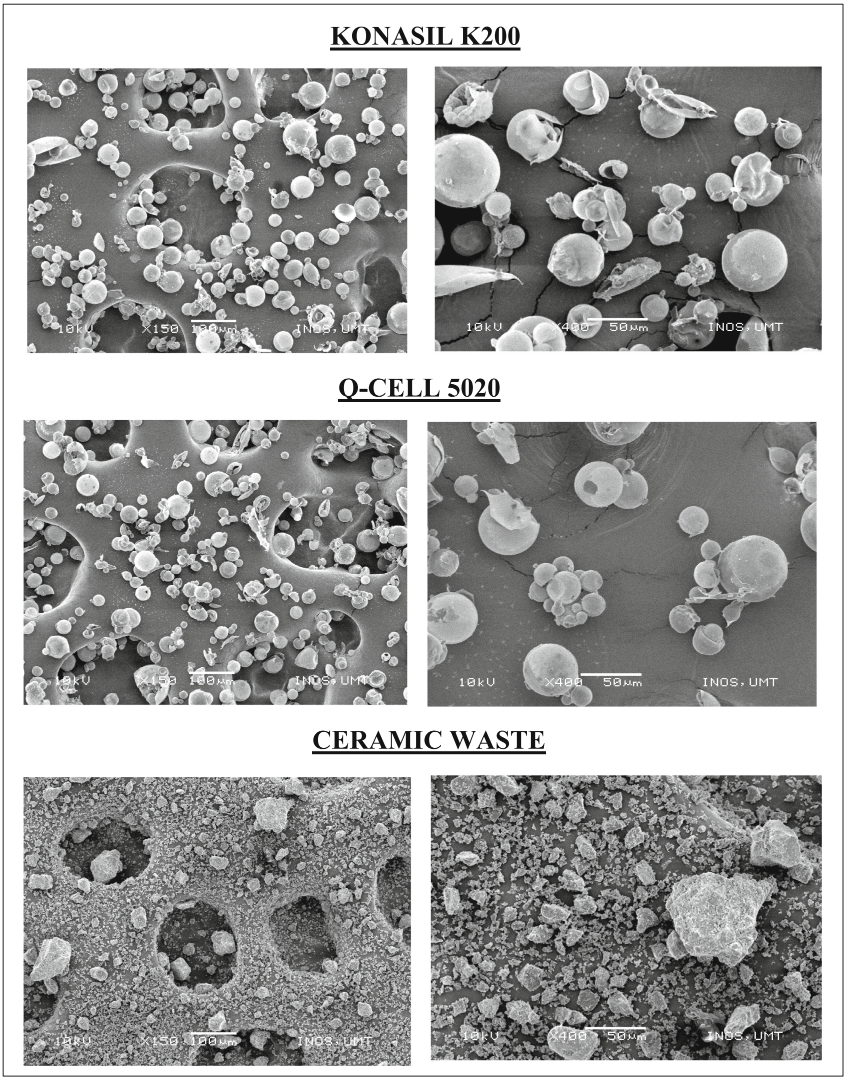

Fig. 3. Microstructure of KONASIL K200, Q-Cel 5020 and ceramic waste particles in 150x and 400x magnification through SEM.

KONASIL K200 has spherical and pure forms. The same occurs for Q-Cell 5020, which contains hollow microsphere forms. Through the properties of these two types materials used for hull production, The microstructure features balloon-type qualities with a density around one-fifth that of ordinary thermoset resins. On an equal weight basis, Q-Cel hollow micro-spheres take up five times the volume of an equivalent weight resin. They have the ability to displace heavy fillers, reducing the weight of composite materials. Because spheres have the smallest surface area, they require the least amount of resin. Lower viscosities are prevalent, allowing less resin to be utilized while increasing production volume, leading in cost reductions in many applications.

When compared to industrial filler, ceramic waste particles have uneven forms and fill voids. In terms of characteristics, this material is composed of crystalline solids with polyhedral individual particles. This is significant because the underlying dynamics of polyhedral particles differ greatly from those of spherical particles, resulting in tighter packing fractions, distinct flow patterns, and percolation.

5 Conclusion

In this paper, the focused on proposed using ceramic waste particles as filler in boat hull production. The properties of this material were being compared with industrial filler in terms of particle size distribution, apparent density and morphology of the particles. It shows that ceramic waste particles have similar properties and suitable to be mix with the industrial filler in several suitable range. For the achievement of the above work, an experimental work was being prepared where all the necessary inputs will be made. Results from mechanical milling (300 rpm, 350 rpm & 380 rpm), mechanical sieving and particle size characterization were related with achievement in characterize physical properties of ceramic waste particles to be used as filler materials in boat hull production (from waste to wealth). Packing arrangement of the specimens show different characteristics for each specimen which will be closely related to the mechanical behavior of the fillers.

In the future, the mechanical and physical properties of ceramic waste particles will be evaluated using the influence of the mixing ratio of ceramic waste particles mixed with industrial fillers and varied ranges of epoxy resin attached to PVC core.

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