Influence of the Scrap Tyre Processing Techniques on the Physical Properties of the Crumb Rubber

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ABSTRACT

The processing mechanism of scrap tyres to produce CR (Crumb Rubber) has a great influence on the properties of the CRMB (Crumb Rubber Modified Bitumen). A fair amount of research was observed in the literature on the bitumen modified by CR processed cryogenically and ambiently. However, little or no work has been done on the CR processed by the other methods such as the Aquablast processing technique, which is a relatively a new waste tyre rubber processing technique within the CR industry. In this study, CR obtained from the two sources; ambient and Aquablast grinding techniques were primarily assessed with a helium pycnometer and SEM (Scanning Electron Microscopy) for their physical properties and appearance respectively. Observations from this laboratory study indicated: (1) the density of the ambient CR was slightly higher than the CR obtained from Aquablast technique; (2) difference in physical appearance was found insignificant.

Key Words: **Crumb Rubber, Crumb Rubber Modified Bitumen, Ambient Crumb Rubber, Aquablast Crumb Rubber.**

1. INTRODUCTION

Increasing traffic density, axle loading and poor performance of bituminous mixtures under unfavorable environmental and loading conditions have resulted in premature pavement failures. In addition, the increased number of vehicles on the roads also generates millions of used tyres every year resulting in environmental and landfill problems.

On the other hand, the development of modified binders has also been witnessed in the last few decades to offset the effects of increased axle loading through enhancement in the pavement performance. Binder additives that have been used in the past include sulphur, rubbers, thermoplastic polymers and thermosetting resins. This was mainly to enhance the mechanical properties under all service conditions [1-3]. In addition to these modifiers, waste materials such as waste tyre rubber have also been used to generate modified binders with added environmental advantage. As a result, improved performance of the virgin binder and mixtures with enhanced resistance to premature pavement failures have also been witnessed in the past [4-5].

1.1 Waste Tyres in Flexible Pavements

The use of waste tyre rubber as a modifier and additive in different bituminous construction not only resolve a used tyre disposal issue but also present the advantage of

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resource revitalization. Moreover, paving industry have shown interest because of the added elasticity imparted to the bitumen and mixture. However, waste tyre rubber used in the paving industry needs to be processed with different techniques to transform it to the required size and shape. When in this condition, it is commonly termed as CR. The common uses of the CR in the pavement industry are described in the following section.

The use of CR in the bituminous industry generally has two different approaches. One is to introduce CR to bitumen as a bitumen modifier and the other is to replace a portion of the fine aggregates with CR particles. Such uses of CR are known as the 'wet process' and the 'dry processes respectively [6]. The wet and dry processes are used to modify the properties of bitumen and bituminous mixture respectively. In the wet process, CR of a certain percentage (15-30% by mass) is blended with bitumen at an elevated temperature for a certain amount of time prior to mixing with aggregates. However, material properties and interaction conditions may vary according to the requirements. The final product has been named differently by different agencies such as "Crumb Rubber Modified Bitumen", "Bitumen-Rubber", "Rubberised Bitumen", "Rubber Modified Bitumen" and "Asphalt Rubber". In the dry process, CR is incorporated as an alternative for a small portion of fine aggregate. The usual percentage of rubber used in this case is 1-3% by mass of the total mixture. In this process, the rubber particles are blended with the aggregate prior to the addition of bitumen to the aggregates. When tyre rubber is used as a portion of the aggregate in the bituminous mixture, the resultant product is sometimes referred to as "Crumb Rubber Modified Bituminous Mixture" and "Generic Mix".

2. CRUMB RUBBER

This is a term usually applied to recycled rubber from automotive and truck scrap tyres. During the recycling process, steel and fabric are mostly removed leaving tyre rubber with a granular consistency. The CR particles are further classified based on their sizes. Granulate is sized by passing through a screen, where the size is based on a dimension (mm) or mesh (holes per inch: 10, 20, etc.). However, market sizes are generally considered in meshes. Mesh refers to material that has been sized by passing through a screen with a given number of holes per inch. For example, 10 mesh CR has passed through a screen with 10 holes per inch resulting in rubber granulate that is slightly less than 1/10th of an inch (0.2mm). The exact size will depend on the size of wire used in the screen.

2.1 Waste Tyre Recycling Process

To produce CR for different engineering uses, tyre shreds and chips are further processed and reduced in size. There are several processes that can be used to produce CR from tyre shred or chip. However, two of the most common are; ambient grinding using various types of grinding mills and cryogenic grinding of rubber by chilling with liquid nitrogen.

Different researchers [7-8] have mainly reported the variation in the surface area as the most important physical property of the CR produced from different techniques. The CR obtained by cryogenic techniques results in a lower surface area in comparison to the ambient processed rubber. This in turn, reduces the reaction rate with hot bitumen. According to research by the Australian Road Research Board, the cryogenic process produces undesirable particle morphology (structure) and generally gives lower elastic recovery compared to the ambient ground rubber [7].

2.1.1 Ambient Grinding

Traditionally tyre rubber is processed by an ambient grinding technique for further use. At room temperature (25°C), tyre shred or chips are processed mechanically to reduce their size by milling and granulation etc. CR obtained with this techniques result in rough texture. To obtain required CR texture, primary and secondary cracker mills are used based on similar principle. This is mainly rotation of rollers with serrations cut in one or both of them. The configuration of the rollers makes them different. The size of the CR is controlled by the gap between the rollers. The magnetic separators are used to remove steel components. Moreover, fiber components are removed using air classifiers. Due to rough texture, the CR particles produced by the cracker mill are typically long and narrow in shape and have a high surface area [7]. The schematic is shown in Fig. 1.

2.1.2 Cryogenic Grinding

Cryogenic grinding is also known as freeze grinding, where any material is cooled at very low temperature to get the material shattered into small particle with even surfaces. The technique is adopted for the material which is difficult to grind to small particle sizes at ambient temperatures due to their soft and sticky appearance. Such material may lead to lumpy masses and result in clogged screens during grinding process.

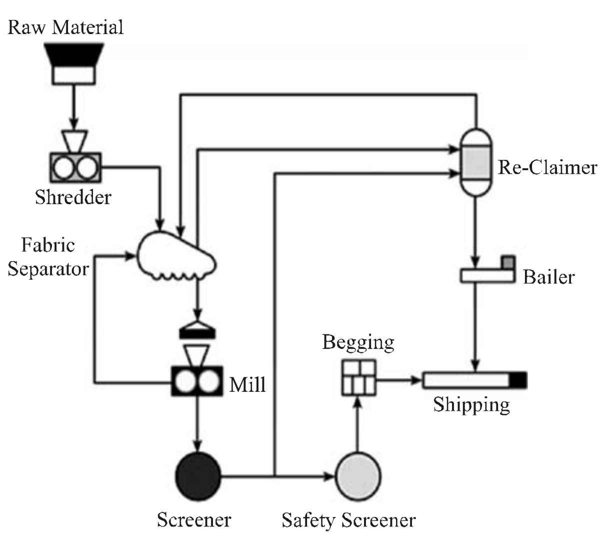


FIG. 1. SCHEMATIC REPRESENTATION OF AMBIENT GRINDING

The cryogenic technique freezes the shredded rubber using liquid nitrogen at a very low temperature even below the glass transition temperature of the material, which is approximately (-72°C). The frozen rubber is then easily shattered into small particles. The steel and fiber part is then removed in almost similar manner as in ambient processing technique. When comparing the two processing techniques, efficient and impurities free CR is obtained in case of cryogenic processing. However, slightly higher cost is required due to the added cost of cooling by means of liquid nitrogen [7]. The schematic of cryogenic grinding is presented in Fig. 2.

2.1.3 Aquablast Processes

Besides the ambient and cryogenic techniques, a new technique has been introduced to process the old tyres to obtain CR known as the Aquablast processing technique. In this process, CR is obtained by applying high pressure water jets with a jet pressure in excess of 350 MPa. However, CR obtained by the Aquablast technique is a relatively new method, which produces a still unknown morphology and properties.

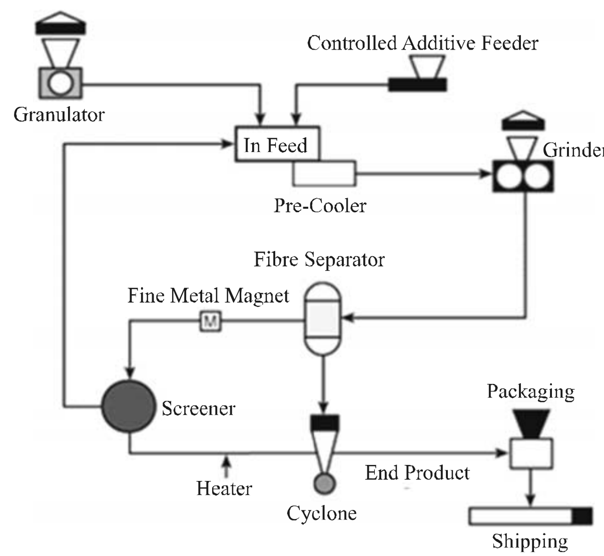


FIG. 2. SCHEMATIC REPRESENTATION OF CRYOGENIC GRINDING

3. CR AS BITUMEN MODIFIER

Of the two primary components bitumen and CR involved during the production of CRMB, later is considered to be the most influential to modify and control the properties of the blend. CR as an elastomeric polymer obtained in a range of sizes and surface textures based on the processing techniques of scrap tyres. In bitumen industry, CR is known to modify the properties of the base bitumen to some extent irrespective of source, type, size and proportion added, when blended at elevated temperatures. However, to obtain the best performance it is important to characterize and compare the modifier from different sources for morphology and physical properties.

The CR selected for this research study was originally from truck tyres but processed by different sources through different techniques. The two different sources based on different scrap tyre processing techniques are Ambient and Aquablast. The objective was to compare the effects of processing nature on the physical properties of the CR. A comparison of the CR obtained from the two sources based on the processing techniques is presented in Table 1.

4. MATERIAL SELECTION

To get a deep understanding and compare the actual differences in the properties of CR from the two sources, material was obtained based on the available market sizes. The selected CR sizes were 30, 40 and 50 mesh, which represent coarse, medium and fine particles respectively.

TABLE 1. CR SOURCES AS A FUNCTION OF TYRE TYPE AND PROCESSING TECHNIQUE

Source	Tyre Type	Tyre Processing Technique	Impurtities (%)
SRC Limited	Truck	Water Jet Grinding	0.4-1
Aquablast Limited	Truk	Water Jetting	0.2-0.5

Size limits based on the available market sizes of the two types of CR are presented in Table 2.

Moreover, the chemical composition of tyres made around the world is considered to be approximately the same. However, physical properties of the CR particles may differ, when scrap tyres are processed with different techniques [9]. To analyse this assumption, the effect of scrap tyre processing nature on the physical properties of CR was compared as a function of surface texture, density and particle size distribution.

5. RESULTS AND DISCUSSION

5.1 Surface Morphology of CR Particles

CR particles obtained from the above production processes were examined using a SEM to get magnified images of the material. This is an electron microscope, which scans the surface of the sample with a high-energy beam of electrons in a rectangular scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties. In this case, SEM was only used to understand the effect of processing techniques on the surface morphology of the CR particles. An illustration and a schematic showing the function of SEM used to capture surface morphology of CR used in this study are presented in Fig. 3.

The SEM images are taken at 400 times magnifications with a working distance of 200μm. Figs. 4-5 present the

TABLE 2. CR TYPE DESCRIPTION BASED ON MARKET SIZES

CR Code	CR Source	Market Size (Mesh No.)	Size Limits (mm)
CR-A No. 30	SRC Limited	30	0-0.6
CR-A No. 40		40	0-0.425
CR-A No. 50		50	0-0.3
CR-B No. 30	Aqublast Limited	30	0-0.6
CR-B No. 40		40	0-0.425
CR-B No. 50		50	0-0.3

surface appearance of 30 and 50 mesh CR particles obtained from the two sources respectively. In addition, CR fractured with the cryogenic method is compared for its surface appearance in Fig. 4.

When CR from the two sources at the different sizes was closely observed for the fractured surfaces with SEM at higher magnification rates, no significant differences were observed between the two sources for surface morphology. As a result, the two sources both showed rough and uneven surfaces. However, CR obtained from ambient grinding displayed more impurities such as fabric compared to the CR obtained from Aquablast fracturing. This also confirmed the data given by the manufacturers (Table 1), where percentage of impurities have been reported as higher for the ambiently ground CR.

5.2 Physical Properties of CR Particles

CR obtained from waste tyres is known to be a porous material with a density ranging from 1.1-1.3 g/cc [10]. Based on its nature and the laboratory experiences, conventional

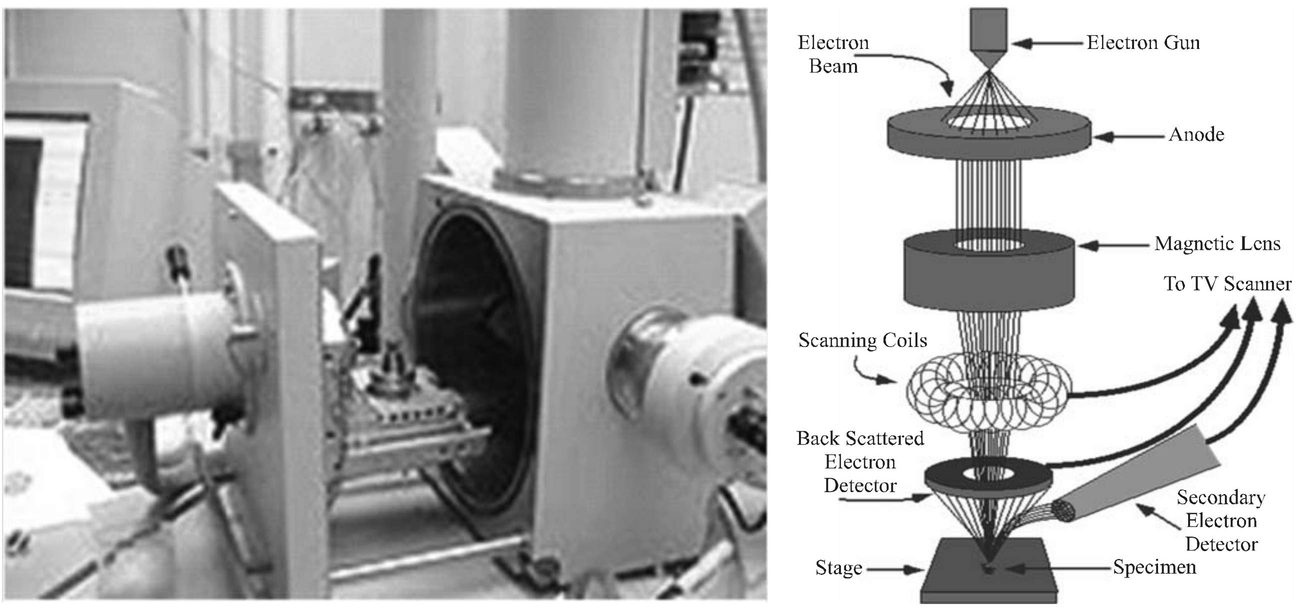
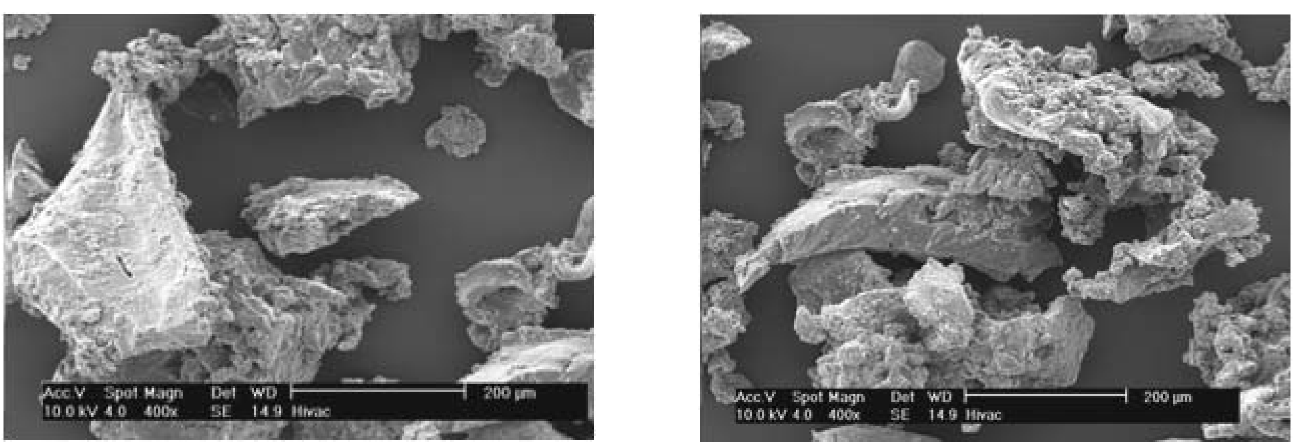


FIG. 3. SCANNING ELECTRON MICROSCOPE (LEFT) AND FUNCTIONALITY (RIGHT)

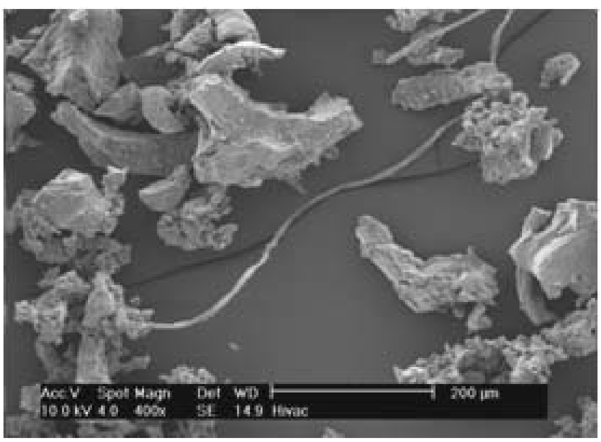


(a) AMBIENT *(b) AQUABLAST CR-30 MESH AT 200 µm AND 400X*

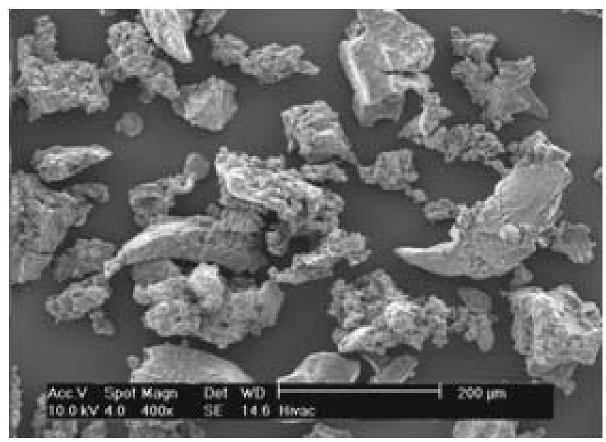
FIG. 4. SEM ANALYSIS

techniques such as water and chemical displacement to measure density were not useful to obtain a true density of the material. When attempting to determine the density of CR with direct measurement of the displaced volume by means of liquids such as water (1 g/cc) and toluene (0.86 g/cc) as a displacement medium, the results were always inconsistent. The reason was understood to be the surface tension, which restricted the liquid medium from penetrating into the open pores of CR particles under ambient pressure. On the other hand, helium in particular due its single atom composition was found to penetrate readily into very fine pores. This method also provided consistent results. Therefore, accurate density of the material was determined with a helium pycnometer, where helium gas as single atoms is used.

The volume of empty apparatus is first determined by introducing a known quantity of helium. A weighed amount of CR is then introduced into the sample tube. The absorbed gases are removed from the CR by an out-gassing procedure and helium, which is not absorbed by material, is again introduced. The pressure is then recorded on a mercury manometer. The volume of helium surrounding the particles and penetrating into the small cracks and pores is then calculated by the application of the gas laws. The difference between the volume of helium filling the empty apparatus and the volume of helium in the presence of the CR sample yields the volume occupied by the sample. Knowing the weight of the material, the density of CR is then calculated. An illustration and a schematic showing the function of the helium pycnometer is presented in Fig. 6.



(a) AMBIENT



(b) AQUABLAST CR-50 MESH AT 200 µm AND 400X MAGNIFICATION

FIG. 5. SEM ANALYSIS

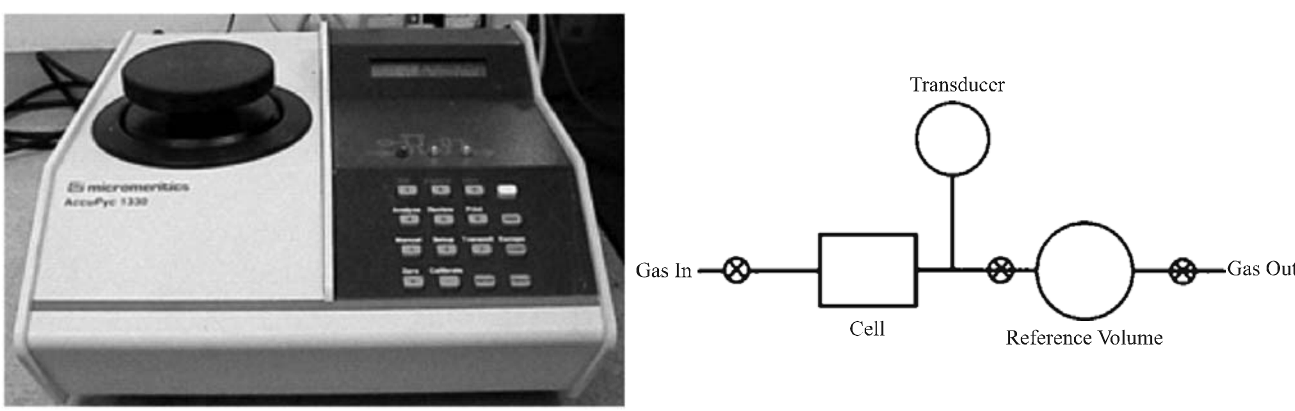


FIG. 6. HELIUM PYCNOMETER (LEFT) AND FUNCTIONALITY OF THE EQUIPMENT (RIGHT)

A comparison has been made by examining the CR obtained from the two sources based on different market sizes of the material. The measured densities with the helium pycnometer are presented in Fig. 7.

In general, increasing density values were observed with decreasing sizes of the CR from the two sources from overall densities measured with the helium pycnometer. However, the two CR sources resulted in slightly different values, when compared with each other at different sizes. As a result, ambiently ground CR particles have shown higher density values with significant differences at lower sizes. From the observations, 30 mesh size from the two sources measured almost same density with 1.17 g/cc, while 40 and 50 mesh sizes resulted in 1.19-1.2 and 1.21-1.22 g/cc densities respectively from the ambient and Aquablast sources.

In addition, to get further understanding of the material, CR sizes were further screened using different sieves and the obtained sizes were again subjected to the calculation of densities. The idea was to compare the difference between the two processing techniques closely. A comparison of the observed densities for the two sources of CR at different screened sizes is presented in Fig. 8.

CR screened with different sieves also followed the same trend as observed during the comparison in overall density of the two sources. As a result, material screened from ambient processed CR had a slightly higher density compared to the other source for all marketed mesh and screened sizes. The difference in the densities of the two sources was quite significant, when smaller particles sizes were compared. However, this decreased with increase in the sizes of the material. As a result, material retained at 0.5mm sieve did not show any significant difference in observed densities.

5.3 Particles Size Distribution of CR Based on the Market Sizes

In addition, the comparison of the two processing techniques in terms of particle size distribution is also presented in Table 3 and Fig. 9 graphical representation of the CR particle size distribution from different sources.

Following the similarities from the observations of the surface morphology and the densities, CR obtained from the two sources has also been shown to have very similar particle size distribution and gradation curves.

6. CONCLUSIONS

The performance of the CRMB is mainly governed by the properties of the CR as modifier. The effect of waste tyre processing techniques on the properties of the CRMB blends has been mentioned by the number of researchers. To assist the fact, CR obtained from the ambient and cryogenic grinding has also been compared for the differences in properties. Besides these waste tyre processing techniques, Aquablast as another technique of processing rubber into finer particles with the help of pressurised water jets has never been looked before. Moreover, the process protocol is relatively new and still unknown to most in the industry.

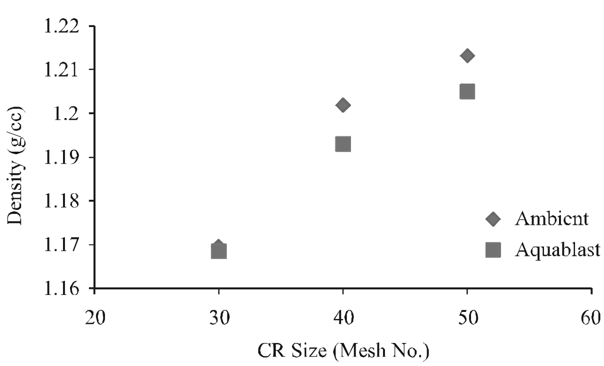


FIG. 7. DENSITIES OF CR PARTICLES BASED ON THE MARKET SIZES

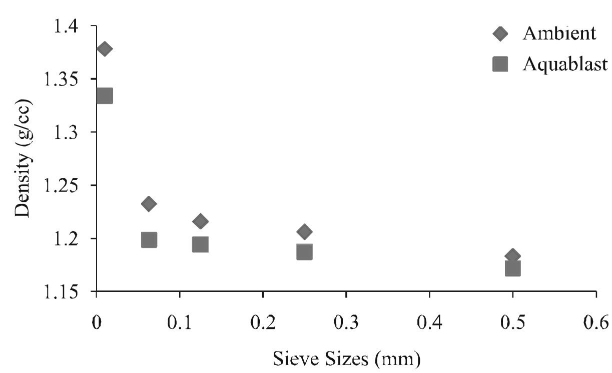


FIG. 8. DENSITIES OF THE CR PARTICLES SCREENED BY SIEVING

TABLE 3. PARTICLE SIZE DISTRIBUTION OF CR SIZES SUPPLIED BY DIFFERENT SOURCES

Particle Size Distribution												
Seive Size (mm)	Ambient CR						Aquablast CR					
	CR-A No. 30		CR-A No. 40		CR-A No. 50		CR-B No. 30		CR-B No. 40		CR-B No. 50	
	Passing (%)	Retained (%)	Passing (%)	Retained (%)	Passing (%)	Retained (%)	Passing (%)	Retained (%)	Passing (%)	Retained (%)	Passing (%)	Retained (%)
1	100	0	100	0	100	0	100	0	100	0	100	0
0.5	65.1	34.9	99.9	0.1	100	0	62.3	37.7	98.8	1.2	100	0
0.25	5.1	60	25	74.9	81.29	18.71	10.9	51.4	37	61.8	76.25	23.75
0.125	0.2	4.9	0.6	24.4	15.6	65.68	1.7	92	47	32.3	21.5	54.75
0.063	0.1	0.1	0.2	0.4	2.1	13.51	0.1	16	0.9	3.8	3.8	17.7
0	0	0.1	0.2	0	0	2.1	0	0.1	0.2	0.7	0	3.8

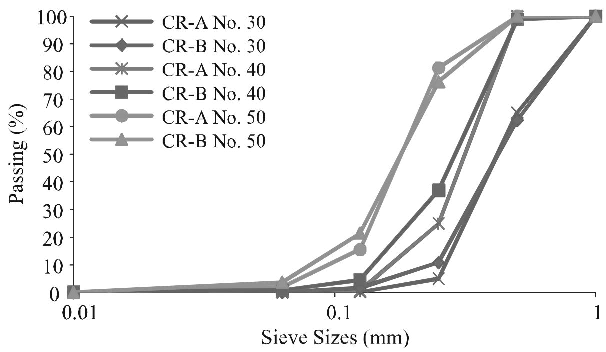


FIG. 9. GRAPHICAL REPRESENTATION OF THE CR PARTICLE SIZE DISTRIBUTION FROM DIFFERENT SOURCES

When two sources were compared for the differences in their properties for their physical properties, a slightly higher density of the ambient CR was observed than the CR obtained from Aquablast technique. However, a difference in physical appearance was found insignificant due to their similar surface texture. Also data given by the source for the amount of impurities was confirmed in the images obtained by the SEM.

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