The Performance of Windshield Glass Waste as a Replacing Material for Coarse Aggregate in Concrete

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Abstract: ***Aggregate mining is an activity that cause ecological imbalance and adverse impact to the environment inclusive of erosion in the coastal and river bank, water pollution, increasing of flood, noise and air pollution. Nowadays, sustainable development has encourage us to sustain the balance between development of the nation and the biodiversity conservation. In order to reduce aggregate mining and promote sustainable development, this study aim to determine the strength and properties of concrete made from windshield glass waste as a replacing material for coarse aggregate. The windshield glass is collected from waste of car windshield at automobile workshop. The concrete cube specimens with size of 100 mm³ were made from different percentage of windshield glass (0%, 10% and 30%). The total of 36 cubes were tested for compressive strength and water absorption, while 18 cylinder specimens were tested for tensile strength in order to obtain the concrete performance at 7 and 28 days. The optimum percentage of windshield glass waste used in concrete as a replacing material was attained at 10% as the value of its strength is higher than normal concrete.***

Index Terms**:** ***Keywords: Aggregate Mining, Sustainable Development, Concrete, Windshield Glass Waste, Coarse Aggregate.***

I. INTRODUCTION

Concrete is a mixture of cement, fine aggregate and coarse aggregate that are derived from natural resources. It is the most commonly used material in structural construction owing to its high compressive strength and durability. Aggregate is one of the main ingredients in concrete mixture. However, the resources of coarse aggregate has been decreasing lately due to its high demand. Furthermore, coarse aggregate can only be obtained from quarries that are non-renewable sources. The Freedonia Group, [2012] has reported that the worldwide demand for aggregates is increasing 5.2% every year through 2015 to 48.3 billion metric tons.

The excessive usage of aggregates along with inconsiderate quarrying and mining has led to depletion of these natural resources that causes environmental problems such as landscape damaging, disruption of eco-system, water, soils and air pollution. All of these impacts to the environment can be minimize by using waste as part of construction materials. Sustainability in construction industry has been widely discussed and issued nowadays as a way to preserve the environment. The current Green Building Rating (GBR) systems evaluate the sustainability of buildings according to various categories of which construction material is one of the category in the systems. Issues like emission of carbon dioxide, use of energy, water, aggregates, fillers and demolition waste in concrete is consider compatible with environmental requirement of a modern sustainable construction industry [2].

Material waste is one of the major environmental problems in Malaysia. Factors such as large population growth, urbanization and rapid economic growth had contribute to the increasing of waste generation. These will affects the climate change and lead to a more serious environmental problems in the future. Therefore, waste recycling has been the ultimate goal to prevent the emission of many greenhouse gases and water pollution. This will stimulates the development of greener technologies, conserves resources and reduces the need of new landfills.

In Brazil, glass waste is the most utilize waste among other various waste generated. In 2011, approximately 3 million tons of glass was produced in which half of it was flat glass that is mainly used in the construction and automotive industries. Automobile production consumed 10% of the flat glass that was fabricated into laminated glass for windshields. These laminated glass windshields consist of two or more flat glass layers that are joined by an organic polymer called polyvinyl butyral (PVB) [3]. The automotive glass waste is usually disposed to the landfills due to the difficulty of separating the PVB from the glass that consequently limit its reusability.

The reuse of waste that is incorporated into construction materials is a good way to preserve natural raw materials,

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save energy, reduce pollutant emissions and eliminate the costs for landfill and concrete production [4]. As our country heading toward a more sustainable and green construction, windshield glass waste has been discovered to be potential replacing material for coarse aggregate in concrete mixture. Windshield glass waste are waste dispose due to car accident or repairing of broken glass that can be found in automobile workshop. The recycling of these waste material as aggregates that are mix with cement and water can produce a concrete. The more strictly government policies in environment regulations has slightly increase the cost involved in disposal and handling of waste material. Therefore, the utilization of windshield glass waste is an alternative way to solve the increasing of waste material, maintaining the natural resources and conserving the ecological balance.

II. LITERATURE REVIEW

A. Sustainability of Natural Aggregate

Natural aggregates is one of the main ingredients in concrete mixture. Conventional concrete generally made of sand as fine aggregate and gravel in various size and shapes as coarse aggregate. Although the worldwide supply of potential aggregate resources is infinite, potential sources of aggregate can only be found in specific geologic environments that must be in a sufficient quality to be use [2]. According to Brito de and Saikia [2013], aggregates typically account for 70–80% of the concrete volume and 92-96% of asphalt pavement. Therefore, aggregate play substantial role in concrete properties such as workability, strength, dimensional stability and durability.

Aggregate mining causes ecological imbalance that damage the biodiversity. These activity will cause erosion in the coastal and river bank, polluting water, increasing flood, noise and air pollution. The effect of mining include landscape destruction and generating of mining waste in the processing site. These problem can be overcome by proper planning and policy implementation. Apart from that, the sustainability of aggregate industry can be increased through the use of waste material as aggregate in concrete production [5].

B. Waste System and Management in Malaysia

The quantity and characteristic of the waste generated is very significant in waste management planning [6]. However, documentation of the data regarding waste generation still limited and not completed compare to European countries [7]. It was estimated about 26 million tons of solid waste is generated in Malaysia [8]. Statistic shows that nearly 50% of the solid waste generated is coming from household, followed by industry, construction and commercial waste [9].

The pattern of municipal solid waste composition in Malaysia since 1975 until 2005 is shows in Table I. The generation of inorganic waste is increasing in average nearly 7% in 2005 which is led by plastic waste and followed by paper, glass and metal waste. This change of solid waste composition pattern and characteristic reflects the change of typical lifestyle of the Malaysian people during this period [10].

Table I: Percentage of the solid waste composition in Malaysia since 1975 until 2005 [11]

Physical composition	Types of solid waste				(%)			
		1975	1980	1985	1990	1995	2000	2005
Organic	Food/Garden	63.7	54.4	48.3	48.4	45.7	43.2	44.8
Inorganic	Paper	7.0	8.0	23.6	8.9	9.0	23.7	16.0
	Plastic	2.5	0.4	9.4	3.0	3.9	11.2	15.0
	Glass	2.5	0.4	4.0	3.0	3.9	3.2	3.0
	Metal	6.4	2.2	5.9	4.6	5.1	4.2	3.3
Others	Others	17.9	34.6	8.8	32.1	32.4	14.5	17.9

In general, the crucial element in waste system in Malaysia are the storage, collection, transportation, treatment and disposal [12]. In fact, the waste management in Malaysia is quite similar with other countries. However, the efficiency of the waste management system is the main constraint existed in Malaysia and most of the developing countries [13]. Hence, recycling is promoted in Malaysia to reduce solid waste before dumping into landfills. Currently, recycling rate among Malaysian is only 5%, which is still low compared to another countries. Thus, the social elements like lifestyles and demographic change need to be considered in the policies for long term policy development of sustainability [10].

C. Utilization of Waste in Concrete

Waste is a by-product of human activities that is generated daily. Modern lifestyle that meet the advancement of technology has led to increase of waste generated and waste disposal problem. Waste accumulation worldwide had caused materials to be left as stockpiles, landfill material or illegal dumping. According to Batayneh et al. [2007], approximately 20% of the building construction waste consists of glass, plastic, and concrete. As the industrialization increases, the amount of waste material is also increasing, which has turned into solid waste issue that should be properly managed [15]. Therefore, recycling is encourage to eliminate these large quantities of waste. Moreover, the environmental impact can be reduced by making more sustainable use of this waste and helps solve waste disposal problem [16].

Pappu et al. [2007] stated that 960 mill tons of solid waste in India is being generated yearly, in which 290 mill tones are unwanted inorganic waste of mining and industrial sector. Common resources are massively utilized while the produced wastes from the industries are increasing rapidly. To safeguard the environment, efforts are being made by using waste in concrete to conserve the natural resources and reduce the cost of construction materials.

Replacing waste material in the form of coarse aggregate for concrete production can be considered one of the environmental benefits that also lead to a better performance in concrete [2]. The utilization of waste material in concrete reduces the cost and become the best environmental solution for management of waste disposal [18].

D. Windshield Glass

Windshield is an integral part of a vehicle structure that also can be define as a plate rigidly mounted on the vehicle's body perimeter [19]. Due to design and location, the windshield is exposed to a wide variety of loads such as wind load, elastic deformation load of a car body as well as the impact load by roadside stones [3]. Hence, the use of protective films can significantly reduce the probability of crack and chips formation in the windshield, but the cost and installation are quite expensive. The compressive strength of this glass is extremely high but its tensile and flexural strength are significantly low. Since the windshield is rigidly fixed on all sides in the vehicle, the bending stress in the glass fixation positions will be much higher than its center [20]. The application of the same load to the different parts of a car windshield reveals that the most vulnerable one is the glass fixation positions [3]. Generally, there are two common type of car windshield glass which is laminated windshield glass and tempered glass. Laminated windshield glass is a type of glass made from two pieces of glass attach to one another using polyvinyl butyral (PVB) transparent plastic. While, tempered glass is a type of glass that is harder and stronger than standard glass [21].

PVB laminated glass (as shown in Fig. 1), is choose in this study due to the higher availability than the tempered glass. In addition, the characteristic of the laminated glass makes it suitable replacing material for coarse aggregate as it is less likely to shatter compared to other glass. This will make the range size of the glass are more uniform and easy to use. PVB laminated windshield glass is considered as one of the most important components for pedestrian protection and vehicle crash safety owing to its resistance of crash during accidents. It possess attribute such as strong binding, optical clarity, adhesion to many surfaces, toughness and flexibility. The windshield glass has more binding effect than other glass which is derived from the laminated glass. The plastic interlayer initially will acts as a binder to hold the glass pieces together to ensure that the glass will not crack. In an attempt to decrease the disposed of waste into the landfill, an alternative way was proposed to utilize windshield glass waste as aggregate in the construction industry. Nevertheless, the reuse of windshield glass waste as aggregate in concrete production is still new and limited due to the difficulty of separating the PVB from the glass [22].

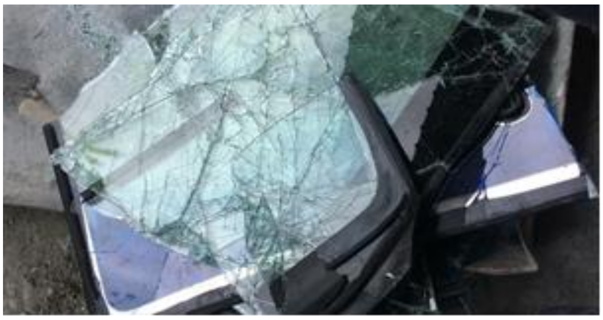

Fig. 1: PVB laminated windshield glass

III. METHODOLOGY/MATERIALS

A. Design Flow Chart of Methodology

The methodology of this study involve the preparation of raw material and procedure in testing of samples that focus on laboratory work. Initially, the concrete samples were prepared based on DOE method. Then, laboratory test such as compressive strength, tensile strength, density, and water absorption was conducted to determine the optimum content of windshield glass waste in the concrete. Data on the performance of the windshield glass concrete was collected to be further analyzed. The flow chart methodology in Fig. 2 briefly explain the materials and methods used in this study.

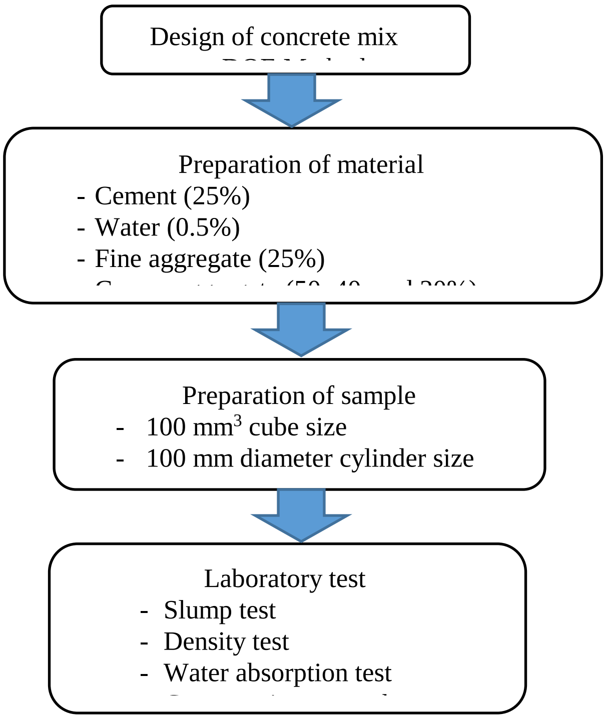

Fig. 2: Flow chart of the methodology

B. Preparation of Material

There are four basic material used in concrete mixture which are Portland cement, coarse aggregate (stone), fine aggregate (sand) and water. Admixture is an optional material that is use to improve the performance of concrete and usually to provide additional cement properties following the requirement ASTM C494. Mixing water with the cement, sand, and stone will form a paste that will bind the materials together until the mix hardens. The strength properties of the concrete are inversely proportional to the water and cement ratio. Excessive water will weaken the concrete while less water use will dry out the concrete but produce workable and stronger concrete. The ratio of aggregate to sand to cement is an important factor in determining the compressive strength of a concrete to produce strong and durable concrete. Table II below shows the common ratio of material used in concrete mixture.

Table II: Material volume ratio in concrete mixture (23)

	Materials volume ratio			Materials required		
Construction	Cement	Sand	Gravel	Cement	Sand	Gravel
				(m^3)	(m^3)	(m^3)
Normal static loads, no rebar, not exposed	1	3	6	0.44	0.38	0.73
Foundations and walls, normal static loads, exposed	1	2.5	5	0.59	0.34	0.69
Basement walls	1	2.5	4	0.59	0.38	0.61
Basement walls, waterproof	1	2.5	3.5	0.62	0.42	0.61
Floors, light duty, driveways, sidewalks	1	2.5	3			
Reinforced roads, walls, exposed	1	2	4			
High strength, floors, columns	1	1	2			

C. Design of Concrete Proportion

The concrete mixture used for specimen and the normal weight concrete mixture was designed by using DOE method shown in Table III and Table IV, respectively. The produce concrete mixture was prepared based on the content of 10% and 30% crushed windshield glass waste for replacing coarse aggregate in concrete. The total value of windshield glass and coarse aggregate used in concrete mixture are shown in Table V and Table VI. The sample of concrete mix designed including the control specimen for cube was test for compressive strength at 7 days and 28 days as shown in Table VII. The total of 36 units of 100 mm^3 cubes and 18 units of 100 mm diameter of cylinder were prepared for each mixture and test for density, compressive strength, tensile strength, and water absorption.

Table III: Concrete mixture proportion ratio for cube specimen based on DOE.

Concrete mixture	Mix proportion ratio				Crushed windshield glass replacement (%)
	Cement	Fine aggregate	Coarse aggregate	W/C ratio	
1	1	1	2	0.5	0
2	1	1	1.4	0.5	10
3	1	1	1	0.5	30

Table IV: Mixture of normal weight concrete (DOE Method)

Quantity	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)		
				10 mm	20 mm	30 mm
Per m^3 (to nearest 5 kg)	360	210	714	-	1116	-
Each mixture 0.003375 m^3 for 1 cube	1.21	0.70	2.41	-	3.76	-

Table V: Total weight of windshield glass as a replacement material of coarse aggregate in concrete mix for per trial mix 3.375×10^{-3} m^3

Concrete mixture	Percentage of windshield glass (%)	Weight of coarse aggregate for 12 sample (kg)	Weight of windshield glass for 12 sample (kg)
1	0	13.18	0
2	10	11.86	1.32
3	30	9.24	3.94

Table VI: Total weight of windshield glass as a replacement material of coarse aggregate in concrete mix for per trial mix 1.571×10^{-3} m^3

Concrete mixture	Percentage of windshield glass (%)	Weight of coarse aggregate for 6 sample (kg)	Weight of windshield glass for 6 sample (kg)
1	0	10.32	0
2	10	9.30	1.02
3	30	7.14	3.18

Table VII: Total concrete test sample for 7 days and 28 days for each percentage

Percentage of windshield glass (%)	Days	Quantity of sample		
		Water absorption test	Compressive strength test	Tensile strength test
0	7	3	3	3
	28	3	3	3
10	7	3	3	3
	28	3	3	3
30	7	3	3	3
	28	3	3	3

D. Concrete Preparation

Concrete was prepared to be test for workability, density, compressive and tensile strength at the age of 7 and 28 days. These are done to ensure the production and placement of quality concrete. The concrete was prepared using cube and cylinder mold according to steps. Firstly, the mold was cleaned up from of all impurities. The inner surfaces of the mold was applied with oil (WD-40 spray) to remove the sample easily from the mold in the next day. Cement, water, river sand (natural fine aggregate), windshield glass waste were weighed based on quantities that have been calculated in DOE Method and was placed in the concrete mixer. Then, the materials were mixed properly by using a concrete mixer. After the mixing process was completed, the concrete mix was filled into the mold and compacted using tamping rod to minimize segregation and avoid vibration compaction. The concrete was released from the mold after 24 hours by using air compressor. Every sample of the concrete cubes and cylinder was labelled with percentage of windshield glass waste, name of test and curing days as shown in Fig. 3.

Fig. 3: Concrete sample of (a) cylinder and (b) cubes

E. Density Test

Density (ρ) of concrete is the mass of a unit volume. Density test is performed by checking the density of harden

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concrete cubes in accordance to BS1881 [1983b] (Determination of density of harden concrete). The test method was conducted using a balance where the samples were weighed and each mass was recorded. Then, the volume of the specimen was determined by measuring the average dimensions. Later, the density of the concrete was calculated using Equation (3.2):

$$\rho = \frac{m}{V} \quad (3.2)$$

Where;
ρ = density of concrete (kg/m^3)
m = mass of concrete (kg)
V = volume of concrete (m^3)

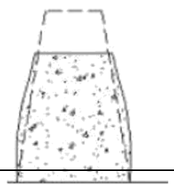
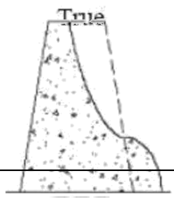
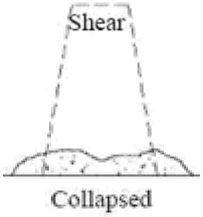
F. Slump Test

Slump test is commonly perform at construction site to determine the workability of concrete. The suggested range for low, medium and high workability of concrete is at the slump value of 25 mm–75 mm, 50 mm–100 mm and 100 mm–150 mm, respectively. Every test conducted is in accordance to the specifications and methods that have been established [25] (Method for determination of slump). The concrete workability is measure based on type of concrete work and divided by the height of concrete slumps (in mm) as shown in Table VIII and Table IX.

Table VIII: Drop of concrete height based on type of concrete work

Type of Concrete Work	Slump Height
Ordinary Concrete (No reinforcement)	23 – 50 mm
Retaining wall and column	75 – 125 mm
Beams and slabs	50 – 100 mm
Road and floor	25 – 100 mm

Table IX: Types of slump

Figure of slump	Types of slump
	True slump is when the concrete only fell slightly without changing the original form of the concrete cone. (until 125 mm)
	Shear slump is when there is sliding at the side of concrete. (until 150 mm)
	Collapsed slump is when the concrete fully fall indicating wet concrete mixture that is regarded as harsh and lean. (150 – 225 mm)

G. Water Absorption Test

Water absorption is defined as the transport of liquid in porous surface due to surface tension by the capillaries [26]. Water absorption test is conducted to determine the sorptivity coefficient of a concrete specimen [2]. Water absorption and porosity are important indicators of concrete durability, where its reduction can greatly affect the long-term performance and serviceability of the concrete [27].

High water absorption ratio in concrete mix will decrease its strength [28]. After the curing process of the concrete cube at age 7 and 28 days, water absorption test was performed to determine the percentage of water absorb in concrete cube. The procedure of the water absorption test was performed based on BS1881 [1983e] (Testing Concrete: Method for determination of water absorption).

Firstly, the weight of the concrete cubes was recorded after the curing process (at the 7th and 28th days) as initial mass. Then, the samples of concrete cubes were placed in the drying oven with each sample not less than 25 mm from any heating surface or from each other. The three samples were dried in the oven for 24 ± 2 hours with the controlled temperature at 105 ± 5 ºC. Upon removal from the oven, each sample was cooled down for a while and then weighed to determine the value of dry mass of concrete cube sample. Next, the concrete cube was immersed completely in the water tank and soaked for 24 hours. After 24 hours, the samples were lifted out from the water tank and shaken to remove any excess water. Later, the samples was dried using cloth until all the water was removed from the sample surface. Each concrete cube sample weight was recorded and the percentage of water absorption for each specimen was determined.

H. Compression Strength Test

Compressive strength test is important in determining the strength and durability of the concrete. This test was performed by referring to BS1881 (1983c)(Determination of compressive strength of concrete cubes). After specified curing time of 7 and 28 days, the concrete cube was removed from water tank and excess water was wiped from the surface. Then, the concrete cube was weighed and recorded. The surface of the concrete compression machine was cleaned from any debris and placed perpendicular to plate testing machine that was centrally on the base plate of the machine. The moveable portion was rotated gently by hand so that it touches the top surface of the concrete cubes. The load was applied gradually without shock and continuously at the rate of 140 N/mm^2/minute until the concrete cube fails as shown in Fig. 4. The maximum load and compressive strength of each concrete cube sample was recorded along with any unusual features in the type of failure was observed.

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Fig. 4: Concrete cube applied with load

I. Tensile Strength Test

Tensile test was conducted to determine the concrete strength when it is pulled apart and when a force is applied in tension. This test was also performed after curing process of the concrete cylinder at age 7 and 28 days which refer to BS1881 [1983d] (Determination of tensile splitting stress). Later, the concrete cylinder was weighed. The procedure is similar to the compressive strength test but it is done by using concrete cylinder to determine its flexural strength. The load was applied gradually on the cylinder at the rate of 140 kg/cm^2/minute until the concrete cylinder fails as shown in Fig. 5. Finally, the maximum load and the tensile strength of each concrete cylinder sample was recorded along with any unusual features in the type of failure was observed.

Fig. 5: Concrete cylinder applied with load

IV. RESULTS AND FINDINGS

A. Concrete Workability

Concrete workability is one of the concrete characteristic that determine the ease of concrete work at the site. Therefore, slump test was conducted against wet concrete to determine the concrete workability and to identify the scale of the actual mixing to produce good concrete. Fig. 6 shows the result of slump test with windshield glass replacement in course aggregate of 0%, 10% and 30%. Based on the figure, the normal concrete mix has a low slump value compared to the concrete mix with windshield glass. This could be due to the windshield glass property that has a relatively low water absorption value compared to normal course aggregate, which produces higher slump.

(a) (b) (c)

Fig. 6: Slump test of concrete mix with windshield percentage of (a) 0%, (b) 10% and (c) 30%

From the observation and data that have been recorded, the value of slump increases with the increasing windshield glass percentage in concrete mix. The relationship between slump and percentage of windshield glass are shown in Fig. 7. The concrete slump increases from 75 mm, 85 mm and 120 mm by replacing course aggregate with windshield glass of 0%, 10% and 30%, respectively. Since the value of the slump are all below 125 mm, the concrete mix samples can be categorized as true slump. The result of this analysis is likely to be influenced by several factors including the chemical properties and the physical form of the windshield glass used. This is because the slump value seems to increase with higher percentage of the glass waste. According to Terro [2006], this could be due to the good cohesion between the glass aggregates that have smooth impermeable surfaces that easily bind in the cement paste.

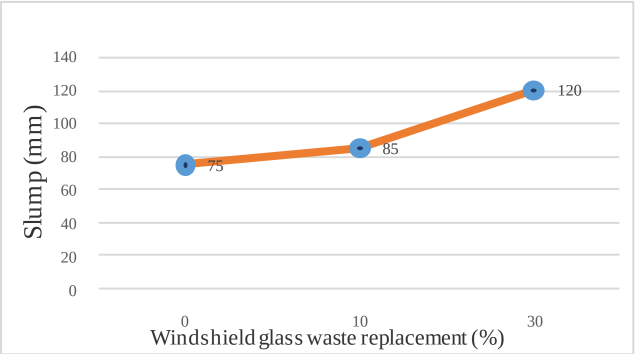

Fig. 7: Slump value with different windshield glass waste replacement as course aggregate

B. Concrete Density

Concrete density is to determine whether the concrete has high quality in terms of strength and optimum weight to facilitate transportation. Fig. 8 shows the result of concrete cubes density at 7 and 28 days. It can be seen that concrete density increases when the hydration period increases and the density is decreasing with the addition of windshield glass into the concrete mixtures. The hardened concrete density at 7 days were 2323 kg/m^3 and 2280 kg/m^3 for replacement of

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course aggregate with windshield glass of 10% and 30%, respectively compared to control sample with 2400 kg/m^3. Similar result was obtained for concrete density at 28 days, in which the concrete density decrease from 2340 kg/m^3 and 2290 kg/m^3 with increasing percentage of windshield glass of 10% to 30% in comparison to control sample of 2416 kg/m^3. This is likely due to the low specific gravity of the windshield glass compared to the course aggregate that reduces the density of the concrete.

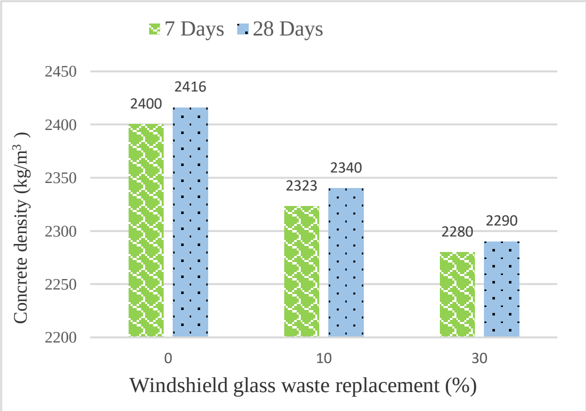

Fig. 8: Concrete density of different windshield glass waste replacement at 7 and 28 days

C. Compressive Strength

The compressive strength test was carried out on hardened and dry concrete cube samples to identify the concrete ability to carry the specific load. For this study the test was conducted on a 100 mm^3 concrete cube which had been cured in water and tested on the 7 and 28 days. Average value of six cube samples data were obtained for each percentage of windshield glass. The results of samples containing windshield glass at 0, 10, and 30% at age 7 and 28 days are shown in Fig. 9.

It can be seen that the 10% replacement of course aggregate with windshield glass have the highest compressive strength of 34.4 MPa at 28 days compared to the 0 and 30% windshield glass waste replacement. This could be due to the physical characteristic of the glass waste that can fill up the voids in the concrete particles that subsequently producing strong bond between the glass and the concrete mixture. This is supported by Srivastava et al. [2014], that obtained similar result in which the optimum replacement level of glass waste can effectively be used as coarse aggregate is at 10%. On contrary, the 30% replacement of course aggregate with windshield glass display slightly lower compressive strength than the 10% with 27.7 Mpa on day 28. This may be due to the excess of the windshield glass waste in the concrete that weaken the bonding in the concrete matrices and consequently lower the strength of concrete [22]. The lowest compressive strength was display by the control sample (0% windshield glass waste) with 15.8 MPa on day 7 and 15.6 MPa on day 28.

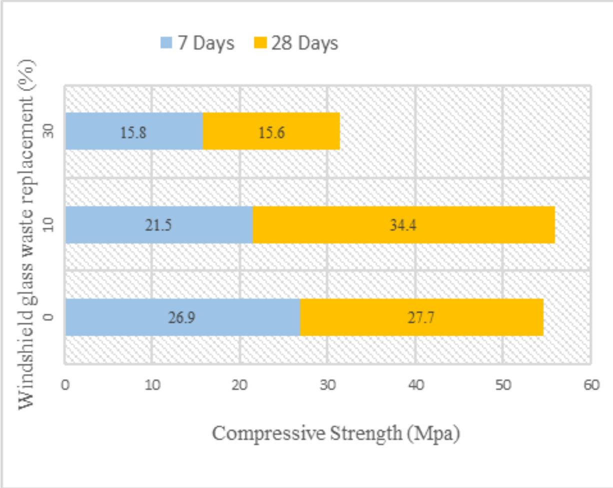

Fig. 9: Compressive strength of different windshield glass waste replacement at 7 and 28 days

D. Tensile Strength

Tensile strength is the ability of a concrete to withstand a longitudinal stress that is expressed as the greatest stress without breaking. The level of stress, size, age and confinement of concrete flexure member are the factors in determining the strength of concrete. Tensile test was perform on a 100 mm diameter of cylinder concrete which had been cured in water and tested on the 7 and 28 days. Six cylinder concrete samples were produced for each percentage of windshield glass waste replaced in the concrete to obtain the average value. Fig. 10 shows the result of tensile strength of the concrete at 7 and 28 days of curing with windshield glass replacement of course aggregates at 0, 10, and 30%.

The result revealed that the replacement of 10% windshield glass as course aggregates has the highest tensile strength at 7 and 28 days with 2.69 Mpa and 3.06 Mpa, respectively. This could be due to good compaction and bonding of windshield glass particles in the concrete that gave the optimum strength at 10% of windshield glass waste. However higher replacement of 30% windshield glass waste result in slightly decrease of tensile strength of 2.53 Mpa at 7 days and 2.51 Mpa at 28 days. In comparison, the control sample recorded the lowest tensile strength of 2.23 Mpa at 7 days and 2.66 Mpa at 28 days.

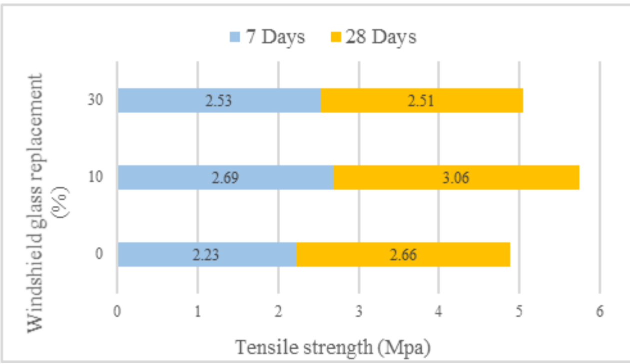

Fig. 10: Tensile strength of different windshield glass waste replacement at 7 and 28 days

E. Water Absorption

The water absorption test is perform using the concrete cube samples prepared at the age of 7 and 28. There are six samples for each percentage of windshield glass and the average result are recorded in Table X. The result shows that the water absorption is the lowest at 10% of windshield glass waste replacement. Less water absorption was recorded at 10% windshield glass replacement compared to other percentage with 2.96% on the 7 days and 4.06% on 28 days. The 30% windshield glass content shows the highest water absorption of 5.27% on the 7 days and 5.43 on 28 days. This indicates high porosity of the concrete mix and the pores were not interlinked. The porosity is associated to higher permeability in the concrete that could have contributed to the decreasing of the concrete strength [22].

Table X: Water absorption of different windshield glass waste replacement at 7 and 28 days

Percentage of windshield glass waste (%)	**Water absorption (%)**	
	7 days	**28 days**
0	5.20	5.30
10	2.96	4.06
30	5.27	5.43

V. CONCLUSION

The windshield glass waste is a suitable alternative material in concrete mix to replace coarse aggregate. The optimum percentage of windshield glass as a substitute for coarse aggregate is at 10%. This is because at 10%, the bond between the windshield glass and the concrete is very effective as the compressive strength of the concrete cube (21.5 and 34.4 Mpa) and tensile strength of the concrete cylinder (2.69 and 3.06 Mpa) almost reach the specified grade on the 7 and 28 days of curing, respectively. However, higher percentage of 30% windshield glass in concrete will decrease its compressive and tensile strength due to high porosity in the concrete mix that weaken the bonding between concrete and windshield glass. In retrospect, the 10% of windshield glass waste replacement for coarse aggregate shows great potential to be utilize in the construction industry as the concrete strength is higher than the normal concrete (without windshield glass waste). This will help to reduce aggregate mining in the future and safeguard the natural aggregate resources as well as the environment.

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