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MECHANICAL PROPERTIES OF CONCRETE WITH RECYCLED COMPOSITE AND PLASTIC AGGREGATES

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ABSTRACT

This project is aimed at studying the influence of incorporating recycled plastic and composite aggregate on the workability, mechanical property, water absorption, and electrical resistance of silica fume concrete. Secondly, the paper will evaluate the possibility to use recycled plastic concrete (RPC) in railway track application (i.e. traditional ballasted track and ballastless track). Two replacements (10% and 20%) of natural coarse aggregate by 3.35mm, 5.6mm and mixed size recycled plastic aggregate are introduced. The experimental results confirm that the workability is improved with an increase in the plastic aggregate replacement. In addition, it is found that mechanical strength and durability in terms of water permeability are reduced, whilst electrical resistance is improved. The result also reveals that application of this environment friendly recycled plastic concrete in railway tracks sustainably can improve ability to absorb vibration energy of railway system.

Keywords: Mechanical properties, recycled composite, plastic aggregates, concrete.

INTRODUCTION

Rapid industrialization and urban development globally have led to many waste handling and disposal problems. The rapid growth affects the uses of raw materials, which are available only in limited quantities. The pressure on finite resources and burdensome wastes results in both economic and societal constraints. The problem of remaining wastes is of major concern around the globe. However, plastic waste is one of materials that have potential for recycling. The management and recycling of plastic waste is rapidly growing. The utilization of recycled plastics in concrete is a partial solution to resolve environment and ecological problem. In this study, the research mainly focuses on the application of concrete to railway tracks and evaluates the feasibility to utilize recycle plastic aggregate concrete. Two type of railway track systems will be analysis and compared including traditional ballasted tracks (sleeper) and ballastless track (Slab Track). A number of experiments will be carried out to evaluate the physical and mechanical properties of the plastic aggregate concrete. The concrete has included Mixed Engineering Polymer (MEP) aggregate as partial replacement of conventional coarse aggregate to create plastic aggregate concrete.

Over the past 50 years, railway systems have been revolutionizing rapidly. The train speed and axle load have come to commuters' primary concern nowadays. Because of these challenges, slab track has been a breakthrough technology to replace conventional ballasted track system. Slab track technology offers a proven higher performance in

services and a longer life span than traditional ballasted tracks. It is a modern form of track construction, which has been used successfully throughout the world for heavy rail, high speed lines, light rail as well as tram systems. Slab track technology offers proven higher performance in service and a longer life compare to traditional ballasted track. Table 1 shows how successful that slab track is constructed around the world.

Table 1 Slab track projects in the world

Project	Country	Track form
Shinkansen	Japan	Shinkansen
Duerne	The Netherlands	Embedded Rail
Best	The Netherlands	Embedded Rail
Crewe-Kidsgrove	UK	BBEST Embedded Rail
High Speed Line HSL-Zuid	The Netherlands	Rheda 2000
Cologne-Frankfurt High Speed Line	Germany	Rheda Zublin
Hibel & Prestbury Tunnels	UK	Rheda 2000
Nuremberg-Ingolstadt High Speed Line	Germany	Rheda 2000FF-Bögl
Taipei and Kaohsiung High Speed Rail	Taiwan	Rheda 2000
Eje Atlantico	Spain	Rheda 2000
Perpignan-Figueras	Spain	Rheda 2000
Guadarrama Tunnel	Spain	Rheda 2000
Beijing-Tianjin Intercity Railway	China	Rheda 2000
TGV Méditerranée	France	Sateba booted sleeper
Channel Tunnel	UK/France	Sonneville block
Channel Tunnel Rail Link Phase II	UK	Booted sleeper
Gotthard Tunnel	Switzerland	Booted sleeper
St. Pancras	UK	Resilient baseplate
Docklands Light Railway	UK	Resilient baseplate
Athens Attiko Metro	Greece	Booted sleeper
Hong Kong MRT	Hong Kong	Resilient baseplate Floating track slab
Kuala Lumpur Star LRT	Malaysia	Resilient baseplate
London Underground	UK	Resilient baseplate
Tramway de Grenoble	France	Booted sleeper
Nottingham Express Transit	UK	Embedded Rail
Sheffield Supertram	UK	Embedded Rail

The design life for traditional ballasted tracks is typically around 50 years. But concrete track slabs (see Fig. 1) offer longer design life up to at least 60 years. In addition, track slab do not require frequent inspections and maintenance. Comparing to ballasted tracks, slab track system is fixed in

position therefore it is not necessary to carry out regular realignment of the rails. By considering the aspect in maintenance and design life, track slab is a sustainable option over a 60 year and 120 year lifecycle.



Fig. 1 A typical slab track

DESIGN PARAMETERS FOR SLAB TRACKS

For the slab track construction (see Fig. 2), a stabilized subbase are required to provide a more uniform distribution of wheel load stresses which reduces the subgrade stresses and provides a degree of frost protection. Stable subgrade is also an important aspect to consider. The subgrade need to be uniform, well prepared, with adequate strength and well drained. Poor subgrade may lead to pier settlement and cause rail deformation. Slab track will exhibit failure such as cracking, faulting and pumping due to poor subgrade condition. The failure modes are similar to concrete pavement. Weak subgrade soil and soils are susceptible to frost heave and should be removed and replaced with compacted granular soil. The adjustments to track geometry after construction are very limited. Hence, special preparation of subsoil before construction is essential.

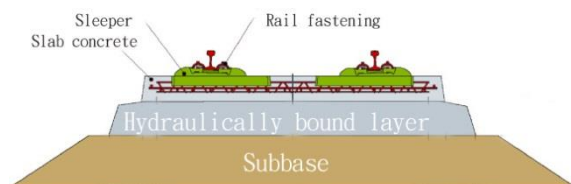


Fig. 2 Typical cross section of a slab track

Concrete used for slab track construction is similar to highway pavement construction. Therefore, material specification developed by the local jurisdiction (state or provincial railway

agencies) can be directly adopted [1]. The followings are the minimum requirements:

- Minimum 28 days compressive strength - 27 MPa
- Minimum 28-day flexural strength - 4.1 MPa
- Cement meeting requirement of ASTM C150
- Aggregate meeting requirement of ASTM C33 A. 25 to 38 mm maximum aggregate size may be used. Special attention should be paid to susceptibility to freezing, thawing and alkali-aggregate reactivity.
- Air entrainment based on exposure condition. Typically 4 to 7% total air content is specified for mild to severe exposure conditions.

RECYCLED PLASTICS

As the world population increasingly growing, much more wastes are being generated. Plastic waste is one of the major issues affecting the globe environment. In the past 50 years, world consumption and production of plastics have continued to go up. 260 million tons of plastic was generated worldwide in 2008, plastic consumption is to reach 297.5 million tons by the end of 2015 [2]. As its nature, plastics belong to a chemical family of high polymers, they are essentially made up of a long chain of molecules containing repeated units of carbon atoms. Because of this inherent molecular stability (high molecular weight), plastics do not easily breakdown into simpler components [3-4]. Therefore, it is very essential to find a sustainable way to solve this issue. It is extreme difficult that the recycled plastic is usable. That's because plastic waste contains many different types of plastic that have to be treated in different ways for recycling. Now, a new method designed to create expanded construction nodules from mixed plastic waste may replace the expanded clay traditionally used in light concrete that is not used for structural part of a building and often contains air bubbles [5-9].



Fig. 3 Mixed plastic waste

Under a project supported by the EU's eco-innovation programme, plastic waste has been successfully converted into a high-performance aggregate for use in making lightweight concrete and mortar, as shown in Fig. 3. However, many researchers have demonstrated that use of recycled plastic in concrete partial replacement of aggregate significantly reduces its mechanical properties dependent on the replacement level [9-17]. Therefore, the recycled plastic concrete still requires further development.

CONCRETE MIX DESIGN

For the concrete mix design used in this research, the proportion of content was calculated by the method documented in the "Design of normal concrete mixes" published by the building research Establishment. Prestressed concrete sleeper (or railroad ties) are usually designed using high strength concrete (around 50-80). Therefore, the control mixes were designed aiming to achieve a target mean strength of 63 MPa (also known as C 50/60) at 28 day. A water-cement ratio of 0.44 was designed on the basis of the target mean strength, the cement strength class and as well as the type of the aggregate. The amount of free water content used to achieve the designed w/c ratio was based on the desired slump, the maximum size and the type of aggregate. Cement content was calculated by the values of w/c ratio and the amount of free water. Mixed engineering polymers (MEP) sizes of 5.6mm and 3.35mm were used to replace 10% and 20% of coarse aggregate using direct volume replacement method. In addition, MEP without sieve was also used to replace 10% of coarse aggregate. Silica fume was also added to replace 10% of cement by volume in all MEP concrete. Due to lack of time, 20% MEP without sieve concrete haven't conduct in the reports. Seven concrete mixtures are prepared (as tabulated in Table 2) for this research program to study the

effect of MEP sizes and their distribution: RFC, SFC, SFRC-5.6-10, SFRC-5.6-20, SFRC-3.35-10, SFRC 3.35-20 and SFRC mix-10.

Cement:

The cement used for the present investigation was Ordinary Portland type 1 with characteristic strength of 52.5MPa according BS EN 197-1.

Aggregate:

Fine aggregate with a maximum particle size of 5mm. Coarse aggregate with a maximum size of 10mm

Silica Fume:

Elkem Silica fume, grade 940 was replace 10% of cement by volume in all recycled plastic concrete to enhancing the machanical properties.

Recycled plastic aggregate:

In this study, recycled plastic aggregates also called Mixed Engineering Polymers (MEP) were used to replace the coarse aggregate to study the property of plastic aggregate concrete. The MEP were kindly supplied by Axion Polymers. This type of MEP is a mixture of clean, wasted granular chips rich in PP with regular particle size. MEP sizes of 6.7mm, 5.6mm, 4.75mm and 3.35 mm were classified from the sieving vibrator. Two different sizes of MEP are used in this study: 5.6 mm and 3.35 mm.

WORKABILITY

Slump tests are carried out to determine the workability of the fresh concrete. The procedure of slump tests complies with BS EN 12350-2. Fresh concrete is filled to the cone in three stages. In each stage, the layer is compacted 25 times with a rod or stick. At the end of the third stage, the protruding concrete on the top of the mould is struck off flush with a trowel. The mould is then lifted vertically upward. Finally, the slump is then measured.

Table 2 Mix design

No	Mixes	Kg/m ³					
		Cement	Water	Gravel	Sand	Silica fume	MEP
1	RFC	530	233	986	630	0	0
2	SFC	477	233	986	630	53	0
3	SFC-5.6-10%	477	233	887.4	630	53	98.6
4	SFC-5.6-20%	477	233	788.8	630	53	197.2
5	SFC-3.35-10%	477	233	887.4	630	53	98.6
6	SFC-3.35-20%	477	233	788.8	630	53	197.2
7	SFC mix-10%	477	233	887.4	630	53	98.6

Workability of concrete is measured in terms of ease and homogeneity with which a freshly mixed concrete or mortar can be mixed, transported to construction site, placed in forms and compacted. The higher the slump, the easily the concrete to mixed, transported, placed and compacted. From the result obtained from the Slump test, replace 10% cement by silica fume to significantly reduce the workability about 50%. The workability can improve by low replacement rate of silica fume around 2-3% by mass of cement, but can reduce workability when added at higher replacement rates. Fig. 4 clearly shows that adding plastic can enhance the workability.

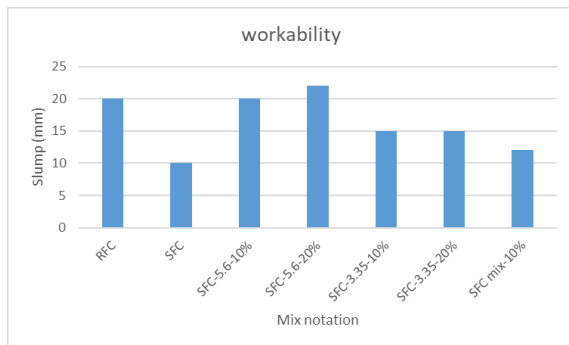


Fig. 3 Slump of concrete

COMPRESSIVE STRENGTH

Six 100mm x 100mm x 100mm cube test were casted per concrete mixture. Three cubes were tested at 7 days and the other three cubes were tested at 28 days. The compressive strength tests were carried out on those cubes. The compressive strength test was conducted according to BS EN 12390-3.

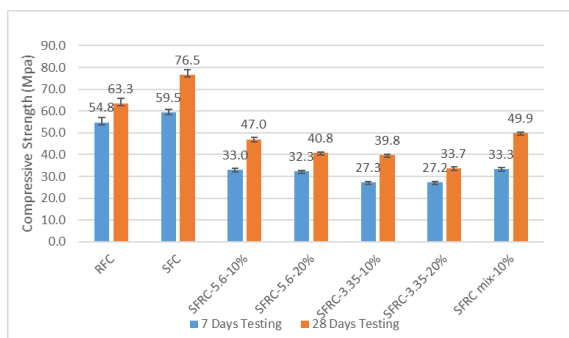


Fig. 4 Compressive strength of concrete

As earlier mentioned, this type of concrete are designed to apply for railway applications either concrete sleeper or slab track. The control concrete (RFC) was designed to have the target mean strength of 62 MPa at 28day in order the meet the minimum requirement of concrete sleeper which is 55 MPa. Each mechanical property value presented in Fig. 4

is the average value obtained from tests performed on three specimens. It can be seen that a reduction in the mechanical strength according to increase in percentage of MEP in the silica fume concrete.

TENSILE STRENGTH

Cylinder splitting test was conducted according to BS EN 12390-6. Three sample of 100mm diameter x 200mm long concrete cylinder per mixture were used. The splitting tensile strength of concrete specimen in MPa was calculated by using the below formula according to BS EN 12390-6

$$f_t = \frac{2P}{\pi DL}$$

where:

f_t is the splitting tensile strength of concrete specimen (MPa)

P is the applied failure load obtained from the testing machine

D is the cross-sectional diameter of cylinder(mm)

L is the cylinder length(mm)

The effect of EMP content on the splitting tensile strength of silica fume concrete show in Fig. 5. At 28-day testing result showed that the splitting tensile strength of all concrete mixes have a similar trend to compressive strength. The SFC still was the highest tensile strength of 3.85MPa which is approximately 22.9% increase compare to RFC.

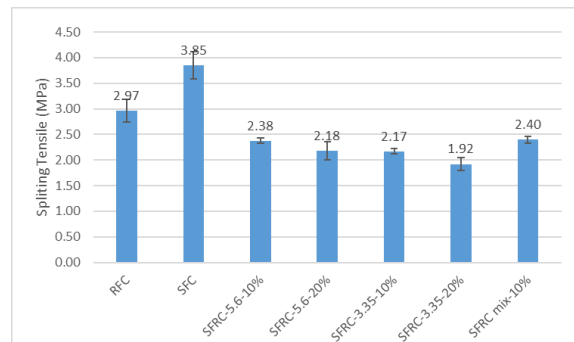


Fig. 5 Tensile strength of concrete

CONCLUSION

This research focused on the study and evaluation of the environment-friendly concrete containing with recycled plastic aggregate (5.56, 3.35 and mixed size) to utilize for railway concrete sleepers and ballastless tracks. Seven concrete mix tests were conducted to investigate the possibility of using those concrete in the railway industry. The test aimed to study the effects on workability and mechanical properties due to the presence of plastic

inside the concrete. The experiment result have showed that the utilization of the plastic material in making concrete can provide an alternative solution to minimize the environmental impact due to unscientific disposal of waste plastic.

The following conclusions are drawn from this study:

- Plastic can enhance workability of concrete which facilitate mix, transport, place and compact process.
- Presence Plastic aggregate will leading to significant reduction in mechanical strength e.g. Compressive and tensile strengths, however adding 10wt % silica fume can slightly compensate the loss of the strength. SFCA – 5.6-10% and SFCA-mix-10% obtain the highest strength compare to other plastic.
- All of the EMP concrete failed to meet the concrete sleeper minimum compressive strength requirement of 55MPa. However all the MEP concrete can be use in ballastless track since all the concrete compressive strength excess 27 MPa
- SFCA -5.6-20% and SFCA-3.35-10% can be used in light weigh concrete such as back-filling trench, pavement, or in nonstructural element which not required high strength.

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