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浮体構造用軽量コンクリート骨材としてのゴムチップの利用技術開発

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POTENTIAL USE OF USED TIRE AS SAND REPLACEMENT IN HIGH STRENGTH MORTAR

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ABSTRACT

Every year, tire generated from vehicles that is not biodegradable are keep increasing, and if not managed properly it bring harm to the environment. Thus, this research was conducted to study the potential of these used tire as mortar material. Crumb rubber from waste tire was mixed as fine aggregate at 10% of sand volume in mortar mixture.　In addition, silica fume is added as a binder at 10% and 15% of cement weight. Six series of rubberized mortar specimen were prepared and tested on its fresh properties, compressive strength, flexural strength, density and elastic modulus. In conclusion, these studies strongly suggest the potential of the crumb rubber to be used as sand replacement with or without silica fume.

Keywords: rubberized mortar, waste utilization, silica fume, compressive strength, elastic modulus, flexural strength

1. INTRODUCTION

In Japan, 1.13 million tonnes of used tire is generated every year which is not biodegradable even after a long period of landfill treatment.　These used tires are mostly used in fuel utilization industries, exported industries and recycling industries.

Research on utilizing this used tire as mortar/concrete mixture component has been started since early 90's [1].　Up-to-date, many successful achievements were reported by researchers around the world. However, in Asian cases, very rare information on the used tire as mixture component can be gathered.　Thus, this research was conducted to study the potential of used tire as sand replacement in mortar mixture. All specimens were tested in the laboratory to identify the fresh properties; air content, workability, fresh density and hardened properties such as compressive strength, hardened density, modulus of elasticity and flexural strength.

2. RESEARCH SIGNIFICANCE

Utilization of used tire as crumb rubber in mortar could be a benchmark to concrete mixture. This will not only give benefits to the government in reduction of providing land for disposal, but also increase the economy growth in various sectors especially amongst construction industry.

3. EXPERIMENTAL DETAILS

3.1 Crumb Rubber as Sand Replacement

The used tire rubber was classified as crumb rubber, (CR) [2]. This CR is a by-product produced from used tire vehicles (car, truck and etc).　The size of the CR ranges between 1 - 3 mm with density of 1.17 g/cm^3 and was used directly as received without any washing procedure as shown in Fig. 1.

In this study, 10% of sand volume was replaced by CR to determine its potential to be used as mixing material.

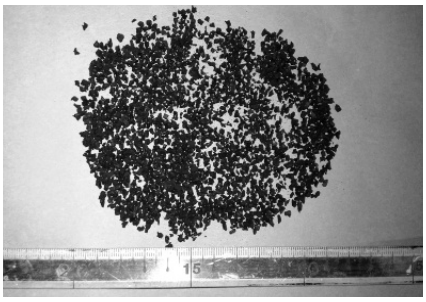

Fig. 1 Crumb rubber

3.2 Other Mortar Mix Component

Sea sand was used as fine aggregate which was in saturated dry surface and 2.77 in fineness modulus. Ordinary Portland Cement, (OPC) and silica fume, (SF) with density of 3.16 g/cm^3 and 2.20 g/cm^3 respectively were used as binder. In addition, silica fume was added at 10% and 15% of cement weight. The ether-based polycarboxylate superplasticizer with density of 1.07 at 20^{o}C temperature was used as chemical admixture at below of 1.5% of 5% maximum dosage allowed based on binder content. Air modifying agent was also used to control the air content. Physical properties of sea sand are shown in Table 1.

Table 1 Physical properties of sand

Physical properties	Sea sand
Density (SSD condition) (g/cm^3)	2.58
Water adsorption (%)	1.72
Fineness modulus	2.77

3.3 Mix Proportion

Six series of rubberized mortar for water to cement ratio of 0.35, 0.30 and 0.25 were prepared as shown in Table 2. Series 1 is a control mixture which indicates the performance level of rubberized mortar. It is expected that CR will reduce the strength [3], thus the target compressive strength for series with CR was set to be at least 50% of control mixture in series 1. Table 3 shows the mix proportion used in this research.

1.4 Description of Mixing Procedure

Mortar mixing was done in a controlled room temperature at 20^{0}C. Cement and water containing chemical admixture was first added and mixed for 30 seconds, followed by ½ sand and ½ rubbers which added alternately until all sand and rubber completed, and was mixed for another 30 seconds. Then, the machine was stopped to allow hand manual mixing. Finally, mixing was continued for an about 60 seconds that makes total mixing time, 2 minutes and 30 seconds. However, for water-to-cement ratio of 25%, total mixing time was extended to 3 – 4 minutes for better homogeneous mixture. All mixing were set at low speed rotation.

Flow test was conducted on a plate and shocked for 15 times for 15 seconds. Meanwhile, air content was measured using pressure method. Then, mortar was casted in a cylindrical steel mould with size of 50 mm diameter and 100 mm length. In addition, 40 mm x 40 mm x 160 mm prism size specimen was also prepared for flexural test. After 24 hours, specimen were de-moulded and placed in water for 7 and 28 days curing under 20^{0}C controlled temperature.

4. RESULT AND DISCUSSION

4.1 Fresh Mortar Properties

Mortar flowability, air content and fresh density was measured after mixing and results are shown in Fig.2, Fig.3 and Fig.4. It was observed that for overall mortar flow performance, the flow

Table 2 Series of rubberized mortar mix

Series	Mixture	Description
1	Control	Conventional mix OPC
2	0CR-10SF	90% OPC + 10% silica fume as binder
3	0CR-15SF	85% OPC + 15% silica fume as binder
4	10CR-0SF	10% crumb rubber and 100% OPC as binder
5	10CR-10SF	10% crumb rubber and 90% OPC + 10% silica fume as binder
6	10CR-15SF	10% crumb rubber and 85% OPC + 15% silica fume as binder

Table 3 Mix proportion of mortar

Description	w/c	Water	Cement	Silica Fume	Fine Agg	Crumb Rubber
				kg/m^3		
Control	0.35	217	619	0.0	1514	0.0
0CR-10SF				62	1442	0.0
0CR-15SF				93	1406	0.0
10CR-0SF				0.0	1364	69
10CR-10SF				62	1292	69
10CR-15SF				93	1255	69
Control	0.30	201	669	0.0	1514	0.0
0CR-10SF				67	1436	0.0
0CR-15SF				100	1397	0.0
10CR-0SF				0.0	1364	69
10CR-10SF				67	1286	69
10CR-15SF				100	1246	69
Control	0.25	182	728	0.0	1514	0.0
0CR-10SF				73	1429	0.0
0CR-15SF				109	1386	0.0
10CR-0SF				0.0	1364	69
10CR-10SF				73	1279	69
10CR-15SF				109	1236	69

decrease with reduction of water in the mix except for series containing silica fume which show increment with increasing of binder. From this figure, even with rubber, mortar indicates the good workability even low dosage of chemical admixture.

Fig. 3 presents the air content result of the mixture. Fedroff et al. [4] reported that higher air content should be expected with rubber as mixture component. However, in this research, it was observed that air content for series 4 (CR only) produced lower air content compared with control mix. This result may be due to the use of air modifying agent. The largest effect can be seen in the mixes with water to cement ratio of 0.35. Air content of rubberized mortar with silica fume rapidly increased. However, this effect is totally contradicted with water to cement ratio of 0.25.

In Fig. 4, it is clearly seen that the density of rubberized mortar decreased due to low density of rubber compared with control mix. Addition of silica fume in the rubber mixture gave additional density reduction. Meanwhile, due to increasing in total binder in the mixture, mixture with w/c of 0.25 show higher density value which ranges from 2.20 g/cm^3 to 2.29 g/cm^3, with w/c = 0.30, ranging from 2.11 g/cm^3 to 2.25 g/cm^3 and with w/c = 0.35, ranging from 2.03 g/cm^3 to 2.25 g/cm^3.

4.2 Compressive Strength and Elastic Modulus

Results are presented in Fig. 5 and Fig. 6. A systematic reduction can be seen in the mixture with CR with and without silica fume in 7 days and 28 days. At 7 days, the minimum strength is more than 30 N/mm^2 which means that all mixture gave acceptable strength value at early stage and it kept increasing until 28 days. In Fig. 6, control mixture (series 1) achieved almost 80 N/mm^2 strength meanwhile the strength for series 4 (CR only) achieved more than 45 N/mm^2 for water to cement ratio of 0.35 and the strength increased for lower water to cement ratio. This shows that, mixture with CR alone gave strength more than 50% of control mixture strength.

Mixture with silica fume gave higher strength value, and when 10% of silica fume was added in CR mixture, it helps to increase the strength up to 35%. However, addition of 15% SF (series 6) gave slightly higher strength compared to 10% silica fume addition (series 5). Thus, it is recommended the use of silica fume to 10% is adequate replacement ratio.

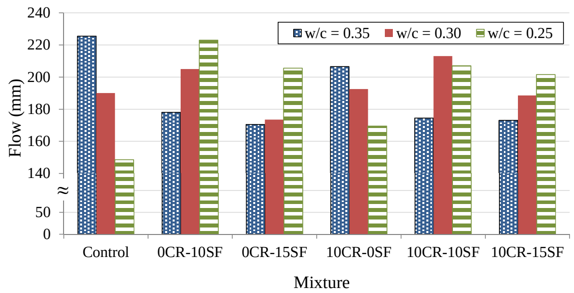

Fig.2 Mortar flow

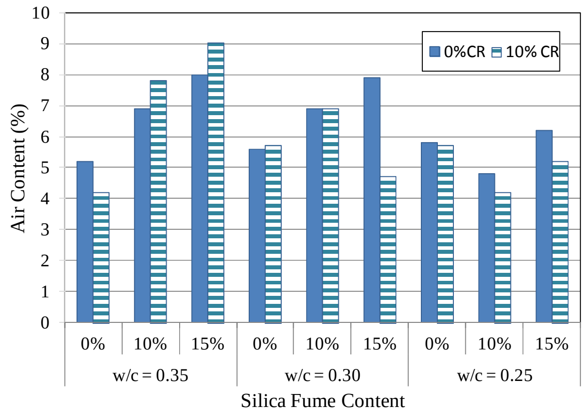

Fig. 3 Air content of the rubberized mortar using pressure method

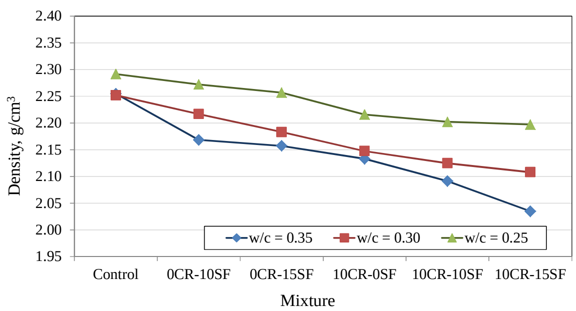

Fig.4 Density of rubberized mortar in fresh state

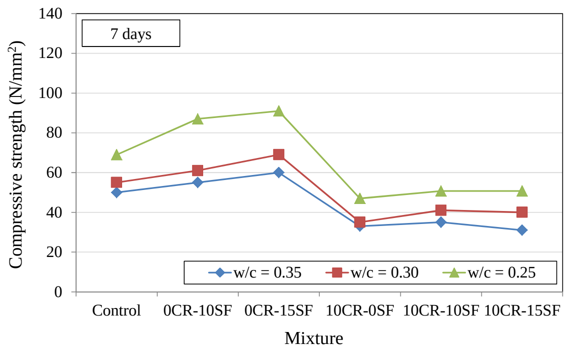

Fig. 5 Strength development of rubberized mortar at 7 days

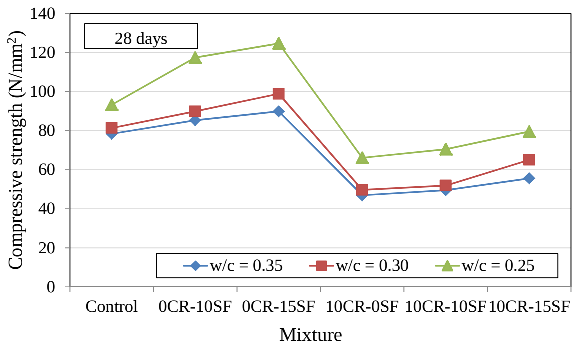

Fig. 6 Strength development of rubberized mortar at 28 days

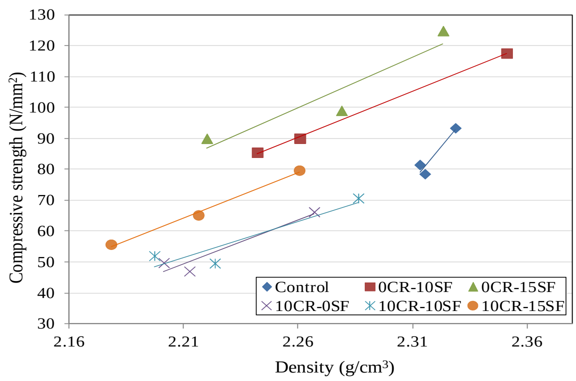

Fig. 7 Relationship between compressive strength and hardened density at 28 days

Relationship between compressive strength and hardened density is presented in Fig.7. Linear relationships are shown for each series mixture and mixtures with CR reduce the density and compressive strength compared to the control mixture with and without silica fume. However, the density decreasing was not more than 10% of control mixture. Thus, in case of producing lightweight mixture, it is possible to increase percentage of the CR rubber at accepted level.

The results of modulus of elasticity test are given in Fig. 8 to Fig. 10. As expected, replacing the sand with CR reduced the elastic modulus. Basically, aggregates with higher elastic modulus gave greater elastic modulus [5]. Thus, the present of CR in the mixture gave lower elastic modulus compared to control mixture. In this study, water to cement ratio of 0.30 gave better relationship between strength and elastic modulus.

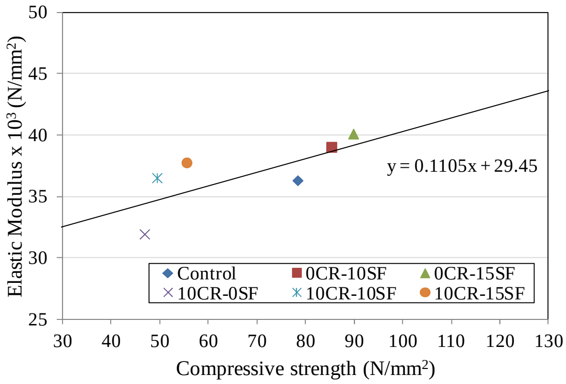

Fig. 8 Relationship between compressive strength and elastic modulus for w/c = 0.35 at 28 days

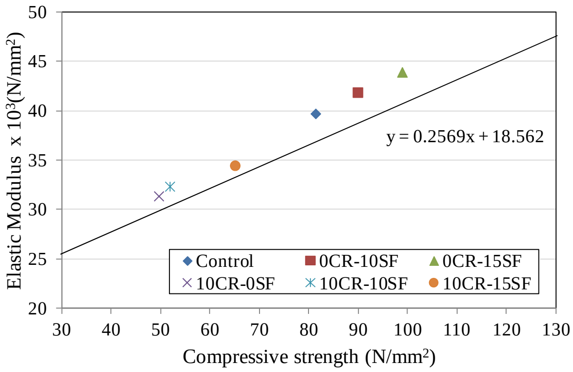

Fig. 9 Relationship between compressive strength and elastic modulus for w/c = 0.30 at 28 days

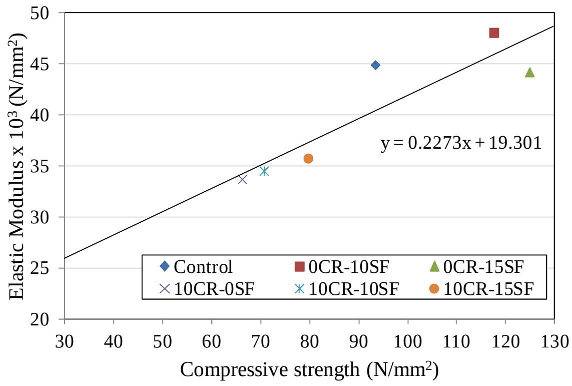

Fig. 10 Relationship between compressive strength and elastic modulus for w/c = 0.25 at 28 days

4.3 Flexural Strength

Fig. 11 show results of flexural strength at 28 days. A clear behavior can be seen from this figure, that is, flexural strength of CR mixture is low. Referring to series 4, a reduction of 10% with respect to the control specimen was observed in the mixture with water to cement ratio of 0.35, and almost 15% reduction in water to cement ratio of 0.30. However, inverse behavior was observed in water to cement ratio of 0.25 where no reduction was occurred. Addition of silica fume in series 4 mixture increased the behavior of rubberized mortar flexural strength.

Table 4 shows the ratio of flexural strength to compressive strength, showing a good ratio ranging from 1/5 to 1/7. From this table, mixture with CR only gave ratio 18.6%, 19% and 18% for water to cement ratio 0.35, 0.30 and 0.25 respectively; where 0.30 gave better result. This indicates that mixture with crumb rubber with no silica fume and mixture of rubberized mortar with silica fume, gave good resistance to brittleness.

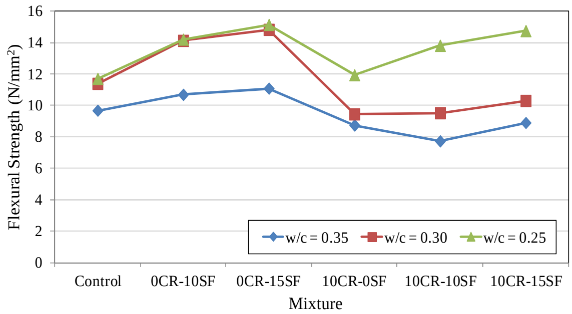

Fig.11 Flexural strength at 28 days

Table 4 Ratio of flexural strength to compressive strength (%)

Description	w/c		
	0.35	0.3	0.25
Control	12.3	14.0	12.5
0CR-10SF	12.5	15.7	12.1
0CR-15SF	12.3	15.0	12.1
10CR-0SF	18.6	19.0	18.0
10CR-10SF	15.6	18.3	19.6
10CR-15SF	16.0	15.8	18.5

5. CONCLUSION

From this research, several conclusions can be drawn as follows,

1. All mixture series gave a good workability with respect to containing crumb rubber with and without silica fume, even low chemical admixture dosage were used.
2. Air content decreased up to 20% reduction for rubberized mortar compared to control mixture.
3. Due to low density of rubber, density of series 4 mix decreased compared to the control mix.
4. As expected, using crumb rubber as mixture component decreased the strength, however, in this research, the strength of rubberized mortar achieved more than 50% of control mixture strength. Meanwhile, elastic modulus also decreased due to low elastic modulus of aggregate. Water to cement ratio of 30% gave better relationship between compressive strength and modulus of elasticity.
5. 10% addition of silica fume in rubber mixture gave 35% strength increment in rubberized mortar; however, the effect of 15% silica fume replacement was also same. Thus, it is suggested to limit the silica fume to 10% addition.
6. In flexural strength test, crumb rubber gave a good resistance towards brittleness and this advantages may be of rubberized.
7. Overall, it is recommended that used of 10% crumb rubber as sand replacement has a good potential to be further study in future especially in concrete mixture with water to cement ratio of 0.35. The use of silica fume can be limited to 10% addition only since 15% silica fume addition gave almost the same performance with 10% addition.

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