A review on waste materials usage as partial substitution in self-compacting concrete

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Abstract. Concrete is the main component in construction which made with the present of cement, water, fine and coarse aggregate. However, conventional concrete suffer from certain deficiencies due to commercial application in construction. In order to overcome the constructability of highly congested reinforced concrete elements, self-compacting concrete is developed. Self-compacting concrete is a type of special concrete which designed to flow into the formwork without any mechanical vibration and possess the ability to consolidate by its own weight without suffering segregation. Common solution for waste disposal is the utilization of waste materials in concrete. Thus, in this review paper the advancements in developing self-compacting concrete by using waste materials such as silica fume, ground granulated blast furnace slag, fly ash, plastic wastes and recycled concrete aggregates were studied to evaluate their effect on concrete behavior.

1. Introduction
Concrete plays an important role in construction which made with the composition of cement, water, fine and coarse aggregate. Due to it useful characteristics, concrete is widely used as construction material. However, conventional concrete suffer from certain deficiencies due to commercial application. In order to overcome the limited construction labors on site, Okamura was first proposed to develop self-compacting concrete. Self-compacting concrete is also developed to resolve the constructability of highly congested reinforced concrete elements. The importance of workability of self-compacting concrete in order to resolve the constructability of highly congested reinforced concrete has been explained [14]. The utilization of super-plasticizer in self-compacting concrete can reduce the amount of water. In addition, self-compacting concrete is defined as a product free of honeycombs and bug holes. The self-compacting concrete is a type of special concrete which designed to flow into the formwork without any mechanical vibration and possess the ability to consolidate by its own weight without suffering segregation [11]. Numerous research to improve durability of self-compacting concrete is carried out. Self-compacting concrete consist higher amount of cement content and hence costly. Therefore, experimental study is carried out to partial substituted filler into self-compacting concrete in order to produce a more economical concrete.

Self-compacting concrete is basically consist the different mix proportions from the normal concrete [3]. It contains less coarse aggregates but it contains a greater amount of ultra-fine materials. It mainly consists cement, water, aggregates and admixtures such as super-plasticizer in order to
obtain high mobility. Current construction demand on self-compacting concrete technology is stated [8]. Self-compacting concrete designed was able to overcome the difficulties to accomplish ideal solidity.

The current market demand on self-compacting concrete were to produce self-compacting concrete with the characteristics of high performance, enhanced quality, high strength and save construction time. Besides that, in order to produce an economical self-compacting concrete, cement presented in the concrete should be substituted by mineral admixtures[21]. The self-compacting concrete integrating with waste materials signify step near to sustainable. Self-compacting concrete performed better and more durable compared to normal concrete because fine materials generate a denser and confined structure [4]. Several waste materials can be added to concrete to improve the concrete behavior. Moreover, waste materials used can aid in reducing the environmental pollution in all around the world by substitute cement or aggregates with certain waste materials [5].

Besides that, with the high volume of cement used in self-compacting concrete production causes self-compacting concrete costly. The partial substitution of fine cementitious materials in self-compacting concrete was the best solution to reduce the cost. With the less usage of cement, the common environmental issue such as global warming can be reduced [13]. The utilization of plastic waste potential to assist government intention to overcome environmental pollution as the existence of plastic contributed negative impact [2]. In this review paper, utilization of various waste materials such as silica fume, ground granulated blast furnace slag, fly ash, plastic wastes and recycled concrete aggregates as partial substitution in self-compacting concrete and their effect on the concrete behavior are reviewed here. The main purpose in this review paper is to compile the innovations development of self-compacting concrete by using waste materials.

2. Silica fume, ground granulated blast furnace slag and fly ash
Various proportions 0%, 5%, 10% and 15% of ground granulated blast furnace slag (GGBS) and silica fumes were utilized as cement substitution in self-compacting concrete. The impact of the cementitious materials to improve the durability and mechanical characteristics of self-compacting concrete were determined. From the result obtained, self-compacting concrete integrating with cementitious materials can performed its better workability and mechanical characteristics than normal self-compacting concrete. The cementitious materials able to reduce shrinkage occurred in self-compacting concrete. In addition, 10% silica fumes showed improvement in hardened characteristics at 28 days [13].

The utilization of mineral admixture in the preparation of self-compacting concrete is evaluated. Discrete amount of mineral admixtures such as fly ash and ground granulated blast furnace slag are prepared as partial cement replacement in producing M30 grades of concrete. Concrete mixes with 25% to 45% of fly ash and 40% to 60% of ground granulated blast furnace slag and also by both combination were prepared in the research study. The outcome of the studies showed the self-compacting concrete with the correct proportions of mineral admixtures possessed good flowing ability and segregation resistance. Moreover, the hardened concrete behavior decreases due to supplementary of mineral admixture in the self-compacting concrete. However, the concrete mix integrating with 50% of ground granulated blast furnace slag showed highest tensile strength. The investigation concluded that the flow is directly proportional with the addition of mineral admixture while the strength is inversely proportional with the addition of mineral admixture as shown in Table 2.1 [18].
Table 2.1. Flexural Strength of Fly Ash and GGBS[18]

| S1.NO | Detail | Fly Ash | GGBS |
|-------|--------|---------|------|
|       |        | M1 10% | M2 20% | M3 30% | M4 40% | M5 50% | M6 60% |
| 1     | Flexural Strength @ 7th day (MPA) | 4.01 | 3.66 | 3.43 | 4.06 | 3.68 | 3.6 |
| 2     | Flexural Strength @ 28th day (MPA) | 4.80 | 4.50 | 4.20 | 4.80 | 4.50 | 4.40 |

Research on the cement replacement by integrating 35%, 55% and 65% fly ash with self-compacting concrete is conducted. Various tests were carried out to investigate the flow ability, filling ability and passing ability. With the intention to measure drying shrinkage and autogenous shrinkage, three samples were casted respectively. Based on the outcome obtained, the drying shrinkage and autogenous shrinkage can be minimized by substituting fly ash into self-compacting concrete because fly ash possessed pozzolanic reaction [10].

The rheological strength properties of self-compacting concrete which comprising fly ash and little amount of super-plasticizer is investigated. Experiment study was carried out where 10% to 30% of fly ash was used to substitute cement. The obtained result presented that the amount of super-plasticizer is inversely proportional to the amount of fly ash. Besides that, the hardened characteristics is inversely proportional with the addition of mineral admixture. The flow ability and passing ability which integrating with the addition of fly ash is obtained as per EFNARC guidelines. Furthermore, the strength of self-compacting concrete in 7 days is reduced more compared to the strength in 28 days. Hence, the conducted research study presented the self-compacting concrete integrating with fly ash available in India generated good performance [9].

The composition of self-compacting concrete containing mineral admixture is optimized. Using optimal composition, self-compacting concrete were developed with the integration of silica fume and super plasticizers and each composition were tested to determine the characteristics of self-compacting concrete. Hardened cylindrical specimens were prepared and tested. A formula is provided for optimal composition [17].

Four different mixes with a fraction of 0% to 30% of fly ash as partial cement supplementary in self-compacting concrete is prepared. Series of experiment program was conducted for M30 concrete grades. Experiment studied the impact of fly ash on the self-compacting concrete were carried out. Based on the obtained result showed 30% of fly ash replacement generated the best performance as shown in Figure 1. However, 20% of fly ash used as partial substitution provided an optimum strength for M30 concrete [11].
Figure 1. (a) Slump Flow Value against Percentage of Fly Ash, (b) V-Funnel Value against Percentage of Fly Ash, and (c) L-Box Value against Percentage of Fly Ash[11]

The mechanical and durability behavior on the partial substitution of silica fume and fly ash in self-compacting concrete is investigated. Four various proportions samples from 30% to 60% of fly ash were utilized to replace cement content and another four similar proportions 10% of silica fumes were added to the composition of 30% to 60% of fly ash. Results showed that with the high volume supplementary of fly ash mainly with the 10% of silica fumes presented the best performance of self-compacting concrete. Besides that, the chloride penetration resistance is enhanced due to the substitution of fly ash and 10% of silica fumes. Moreover, the modulus of elasticity of self-compacting concrete with the substitution of 50% fly ash and 10% of silica fumes showed not affected. In addition, for experiment conducted only fly ash and experiment conducted for fly ash with silica fume shown
better compressive strength after freezing and thawing. However, the splitting tensile strength is inversely proportional with the increase amount of fly ash [22].

3. Plastic wastes
Laboratory test to investigate on reinforced self-compacting concrete integrating with unused plastic fibers is carried out. 9 specimens with percentage of 0.0%, 0.25%, 0.5%, 0.75%, 1.00%, 1.1%, 1.2%, 1.3%, 1.4% of unused plastic fibers by volume of concrete were submersed into magnesium chloride solution for 30days, 60days and 90days to test on its chloride resistance. The chloride resistance of the specimens are determined. For fresh concrete, lower flow ability is obtained from the results when percentage of unused plastic fibers were increased. The maximum percentage of unused plastic fiber shall be 1.4%. This is because more than 1.4% of unused plastic fibre will require greater than 0.86% of super plasticizer as it cause bleeding and segregation. In the hardened state, the compressive strength is inversely proportional to the fibers percentage. Based on the results shown, the highest compressive strength and split tensile strength are obtained while tested on 1% of unused plastic fibers. Therefore, the research determined the utilization of unused plastic fibers integrating into reinforced self-compacting concrete are enhancing the concrete durability against chloride attack [20].

The 25% to 100% of plastic wastes is substituted as coarse natural aggregates in the development of self-compacting concrete mixes and 10% silica fume was prepared to substitute cement weight for each mixes. The fresh and hardened characteristics were evaluated. Based on the data obtained, self-compacting concrete integrating with plastic wastes showed better ability to flow, passing and filling. The result also presented that the resistance to segregation is decrease with the substitution of plastic wastes. Nevertheless, the utilization of plastic waste causes a significant negative impact in density and hardened concrete characteristics. 25% of plastic waste integrating with self-compacting concrete can be used to develop structural light weight aggregate. Self-compacting concrete prepared with distinct proportion of plastic waste showed higher water absorption compared with the mixes without plastic waste [21].

The utilization of unused plastic as partial supplementary of sand in self-compacting concrete is reviewed. In order to obtain accurate data, various proportions of mixes were tested at 0.32 water to binder ratio and binder content of 520kg/m$^3$. The research consideration were 0%, 2.5%, 5%, 7.5%, 10% and 12.5% of six unused plastic contents and three distinct sizes of unused plastic(fine, coarse and mixed unused plastic). From the conducted experiment, the utilization of fine unused plastic is resulted the highest compressive strength as compared to coarse and mixed unused plastic as shown in Figure 2. Based on the result obtained presented that different sizes of unused plastic can be successfully replaced sand content in the self-compacting concrete [6].

![Figure 2. Compressive Strength against Plastic Waste Content](image)

PET bottles waste plastic fibers is added into self-compacting concrete to investigate the effect on its properties. 8 specimens with percentage of 0%, 0.25%, 0.5%, 0.75%, 1%, 1.25%, 1.5%, 1.75% and
2% by volume of concrete were tested at 0.35 water-to-binder ratio and binder content of 490kg/m³. From the experiment result, by adding of waste plastic fibers in self-compacting concrete had better flowing capability of self-compacting concrete. Moreover, the compressive strength of wastes plastic fiber self-compacting concrete can be easily achieved more than 40MPa at 7th day. It also showed that it could achieve up to 76MPa at 28th day. However, the lowest compressive strength obtained are from 1% of waste plastic fiber. Based on the result findings, it can be concluded that PET bottle waste plastic fiber could help self-compacting concrete achieved better workability and strength [1].

The utilization of plastic waste as partial sand supplementary in self-compacting concrete is conducted. Experiment research was conducted by using 0%, 10%, 20%, 30% and 50% of plastic waste. The conducted experimental results showed that 50% of plastic waste integrating with the mortar generated advance experimental outcome compared to other content of plastic waste in term of the materials density. In addition, the experiment investigated that 50% of plastic waste able to produce lightweight mortars. Figure 3 showed the mixes of 50% plastic waste integrating with self-compacting mortar [19].

![Figure 3. Mixes of 50% plastic waste integrating with self-compacting mortar](image)

### 4. Recycled concrete aggregates

The rheology behaviour of self-compacting recycled concrete at fresh stateis investigated. Experimental studies were carried out by substituted the natural coarse aggregates with recycled aggregates with percentage of 20%, 50% and 100% by volume with two type of water to cement ratio. Two tests were tested by using rheometer after 15 minutes from the starting of mixing the water and cement. Stress growth test and flow curve test results were obtained. From the results shown, the researchers found that the self-compacting recycled concrete relying on the water absorption of recycled aggregates and amount of water added to cover the water losses from the high water absorption by recycled aggregates. From the findings of the researchers also showed that the self-compacting recycled concrete curves have higher slope than the normal self-compacting concrete. Hence, researchers predicted that the self-compacting concrete with recycled aggregates have high rheological variation and especially with lower water cement ratio [7].

The utilization of recycled concrete aggregates in self-compacting concrete on the time dependent behaviour is investigated. 0% to 40% of fine and coarse recycled concrete aggregates are prepared. The investigated results showed that 40% of recycled concrete aggregates substitution is possible in the production of self-compacting concrete. In addition, self-compacting concrete incorporating with recycled concrete aggregates possess high mechanical characteristics due to the more confined concrete. The long term properties such as creep behaviour and pores size distributions are affected compared to shrinkage behaviour. Figure 4 showed the cross section of hardened concrete for 0% to 40% of fine and coarse recycled concrete aggregates substitution [12].
The suitability and effect of using coarse recycled concrete aggregate in self-compacting concrete is investigated. Experimental studies were performed with varying proportion of 0% to 100% coarse recycled concrete aggregate with increment of 20% to obtain the fresh properties, strength and durability investigations. Various tests were conducted including compressive strength, split tension test, water absorption, acid attack and chloride ingress. The obtained result was observed that the mixes containing coarse recycled concrete aggregate gains early strength due to the partial hydrated cement adhered to aggregate which accelerates the hydration process. The research studies showed that value up to 40% of coarse recycled concrete aggregate can be effectively use to develop self-compacting concrete without any significant reduction in strength and durability such as acid attack and chloride attack [16].

The utilization of the varying content of recycled coarse aggregates and compared self-compacting concrete with the normal concrete is presented. 10%, 20%, 30% and 40% of recycled coarse aggregates were prepared to partially substitute the coarse aggregate. Based on the compared result presented that the mechanical behavior of self-compacting concrete is affected by substitution of recycled concrete aggregate. The obtained strength is less than normal concrete and these strength decrease with the increase of recycled concrete aggregate amount. 30% of recycled concrete aggregate substitution showed the desirable and better mechanical characteristics. Recycled coarse aggregates showed higher water absorption compared to normal concrete [15].

5. Conclusion
In the review paper, recent advancement in developing self-compacting concrete and the concrete behavior have been reviewed. Varying percentages of waste materials were used to partially supplementary and integrating with self-compacting concrete. Various conducted experiment presented mineral admixtures causes self-compacting concrete to possess good flowing capability and segregation resistance. The mineral admixtures acted as filler to fill up the tiny spaces in the concrete. The investigation concluded that the flow is directly proportional with the addition of mineral admixture while the strength is inversely proportional with the partial cement replacement. Due to the weight of plastic waste, it able to volumetric substitute natural coarse aggregate in order to develop structural light weight aggregate concrete. Based on the research carried out, the results presented the self-compacting concrete properties are retained with the partial supplementary of recycled concrete aggregates and their good qualities stimulate high mechanical properties. In summary, adopting of several waste products in self-compacting concrete possessed optimistic effect and good quality of self-compacting concrete can be produced.
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