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A REVIEW ON PERFORMANCE OF WASTE MATERIALS IN SELF COMPACTING CONCRETE (SCC)

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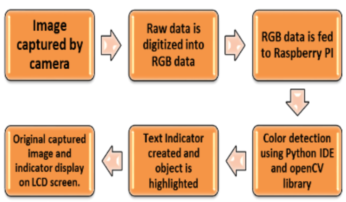
Graphical abstract



Abstract

Self-compacting concrete (SCC) was first developed in late 80's in Japan. SCC is well known for its self-consolidation and able to occupy spaces in the formwork without any vibration and become new interesting topic in Construction and Building Materials Research. There were various SCC researches that have been carried out in Turkey, Malaysia, Thailand, Iran, United Kingdom, Algeria, and India.The aim of this review is to summaries the alternative material used in the mix design from 2009 to 2015 through available literature. It hascommon materials such as Limestone Powder (LP), Fly Ash (FA), Silica Fume and Granulated Blast Furnace Slag (GBFS). While there are many alternative or recycled material can be used in producing SCC. This review only focus on waste material fromMarble Powder (MP), Dolomite Powder (DP), Crump Rubber (CR), Recycled Aggregate (RA) and Rise Husk Ash (RHA).Each type of materialshassimilarity effect in fresh and hardened state of SCC. Therefore, this paper will provide significant and useful information to those new to SCC and fellow researchers for future studies on SCC.

Keywords: Mix design, alternative materials

Abstrak

Konkrit padat sendiri (KPS) telah dihasilkan pada penghujung 80'an di Jepun. Konkrit padat sendiri dikenali sebagai konkrit yang mampu memenuhi ruang di dalam kotak acuan tanpa memerlukan bantuan dari proses getaran dan ia menjadi topik yang menarik di dalam bidang Kajian Pembinaan dan Bahan Bangunan. Terdapat banyak kajian dilakukan di Turkey, Malaysia, Thailand, Iran, United Kingdom, Algeria, and India. Tujuan ulasan ini adalah untuk meringkaskan bahanalternatif yang digunakan di dalam rekabentuk bancuhan bermula tahun pada 2009 sehingga 2015 berdasarkan kajian literatur. Bahan yang biasa digunakan adalah seperti *Limestone Powder (LP), Fly Ash (FA), Silica Fume* dan*Granulated Blast Furnace Slag (GBFS)*. Manakala bahan alternatif atau bahan kitar semula adalah *Marble Powder (MP), Dolomite Powder (DP), Crump Rubber (CR), Recycled Aggregate (RA)* and *Rise Husk Ash (RHA)*. Setiap bahan mempunyai kesan persamaan terhadap keadaan selepas bancuhan dan keadaan selepas keras KPS. Oleh itu, ringkasan ini akan dapat memberikan maklumat yang berguna kepada penyelidik baru dan penyelidik sedia ada untuk kajian yang selanjutnya berkaitan KPS.

Kata kunci: Reka bentuk bancuhan, bahan alternatif

1.0 INTRODUCTION

Developing Self Compacting Concrete (SCC) was started in late '80s in Japan. It was introduce by Okamura Hajime [1], [2]due to shortage of manpower on site and to resolve environmental issue such as noise reduction. This concrete technology has received demand from construction industry in Japan to construct new bridges, buildings and rehabilitation works on site.

By definition, SCC is a concrete that can flow and fill the gap between reinforcement and fill the void inside the formwork at every corner by it is own weight without vibration process [3], [4]. The utilizing of SCC in construction industry in Japan has proved beneficial economy value in several factors such as reduce construction duration, reduction numbers of manpower on site, provided better surface finishes, easier placing handling on site, created greater freedom in design structural (shape and sizes), able to applied at thinner concrete sections, eliminate vibration process (reduce noise levels) and created safer working environment [3], [5].

However, the development of mix design for SCC still under continues research. This was confirmed by the summary from available literature review through wide range of countriesas shown in Table 1 (2009 to 2015). Researchers are looking on utilizing an alternative material from various types of wasteas replacement or additive material in SCC.

Table 1 Mix Design Using Addition Materials

Tahun	Ref.	Country	Mix Design
2009	[6]	Turkey	Mix design using marble powder (recycled value)
	[7]	USA	Mix design using foundry silica dust as replacement for FA (economic value)
2010	[8]	Greece	Mix design cement, SF, Nano SF, LS, P & FA for viscosity effect
	[9]	India	Mix design cement replacement using SF Vs LS, QD & CI (comparison water absorption)
2011	[10]	UK	Mix design (DP + FA) Vs (LS + FA). Utilizing DP as alternative materials
	[11]	Italy	Mix design. Comparison between FA, LP, (Rubble Powder + Fine Recycle) & (RP + Course Recycled)
	[12]	Turkey	Mix design using FA, GBFS, LP, BP and MP for cement replacement
2012	[13]	Algeria	Mix design using various sand
	[14]	Turkey	Mix design MP, LS & FA as filler
	[15]	Turkey	Mix design of cold bonded FA as light weight aggregate
	[16]	Uruguay	Mix design using cement kiln dust (CKD) as a filler
2013	[17]	Portugal	Mix design using fibre
	[18]	Brazil	Mix design using kaolin waste
	[19]	Algeria	Mix design using various sand (RS, CS & DS)
	[20]	Taiwan	Mix design FA & slag with difference w/c ratio
	[21]	Indonesia	Mix design using roof tile powder
	[22]	UK	Mix design using FA & LP as a filler
	[23]	India	Mix design using recycled aggregate
	[24]	Thailand	Mix design using untreated RHA & PFA
	[25]	Thailand	Mix design using cathode ray tube waste
	[26]	Thailand	Mix design using recycled alumina as fine aggregate replacement
2014	[27]	Greece	Mix design using ladle furnace slag and steel fiber reinforcement
	[28]	Turkey	Mix design using LLFA & GBFS as cement replacement & MC as aggregate replacement
	[29]	Iran	Mix design effect of aggregate sizes
	[30]	Turkey	Mix design utilizing of VMA to reduce fine material
	[31]	Malaysia	Mix design using POC as LWA
	[32]	UK	Mix design using RLP & RCA
	[33]	Malaysia	Mix design using Metakaolin with difference course aggregate properties
	[34]	Malaysia	Mix design using RHA and blended fine aggregate
	[35]	Turkey	Mix design using waste marble and recycled aggregates
	[36]	Malaysia	Mix design using Bottom Ash
2015	[37]	India	Mix design using RHA
	[38]	China	Mix design using FA & GGBFS
	[39]	China	Mix design using recycled plastic particles
	[40]	Germany	Mix design containing various mineral admixtures for high performent concrete
	[41]	Tunisia	Mix design using marble and tile waste as filler
	[42]	Algeria	Mix design using seashell as fine aggregate

From Table 1, the most common addition materials are FA, SF, GBFS and LS [3], [43]. While currently researchers have looking forward to make used of recycled material such as Quarry Dust (QD), Dolomite Powder (DP), Limestone (LS), Rubble Powder (RP), Recycled Aggregate, Marble Powder (MP), Cement Klin Dust (CKD), Roof Tiles, Rise Husk Ash (RHA) and Palm Oil Clinker (POC). Some of those waste materials are from construction industry and also from by product industry. All these waste materials are potential as replacement material or substitution materials for fine aggregate, cement or filler materials.

As a conclusion, utilizing of waste material in developing SCC is a good contribution in order to reduce environmental pollution. This effort is not only benefit to environmental solution but it is also can help to generate economic value to the related industry through their abundant waste materials. Therefore, a review on performance of waste materials from previous researchers is an advantage for new researchers to produce sustainable concrete product by utilizing local and available waste materials especially for Malaysian researchers.

2.0 MIX DESIGN

Self Compacting Concrete (SCC) was introduce by Okamura Hajime in 1986 and he has proposed a mix design method for SCC in 1993 [1]. SCC is a concrete that have a capability to flow by it is own weight to fill a void in a formwork and passing through reinforcement bars in the formwork with out using vibration tools as normal concrete during placing the concrete mix. During the placing, SCC will do self leveling without having segregation [1], [2], [3], [43]. Therefore, SCC will be evaluate the fresh state characteristic through several test such as slump flow, time flow during slump test, passing ability using J Ring, stability using V Funnel and L Box test[3].

The idea of SCC proportions was shown in Figure 1 [4]. This method have been classified as empirical design method [44]. In 2001, Nan Su has proposed simplified empirical design method for easier implementation. It was claimed that simplified method could save time, save cost and using small amount of binders. The principal of this method is to create workability by using certain amount of paste material to bind each aggregate material around it during fresh state and improve strength at hardened state [45]. This method classified as close aggregate packing method [44].

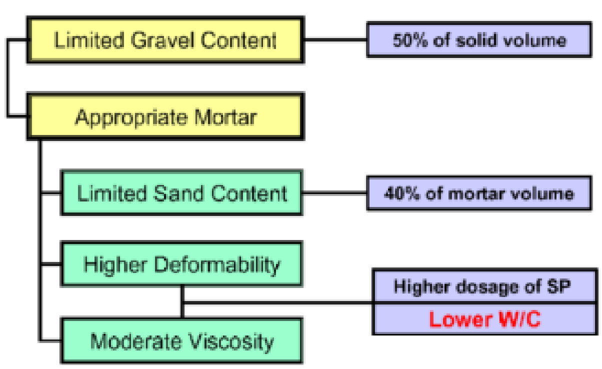


Figure 1 Methods for achieving self compactibility by volumetric ratio (%) [4]

In 2006, Domone has come out with an extensive analysis for 11 years from 1993 to 2003. It was conclude that, SCC should contain lower volume of coarse aggregate contents, high volume of paste, high powder contents, low water/powder ratios, high super plasticizer doses and sometimes required viscosity modifying agent [46].

In 2015, Caijun have summarized a review on mix design method for self compacting concrete[44]. Base on the review, mix design method can be classified in five categories,

1) Empirical design method
2) Compressive strength method
3) Close aggregate packing method
4) Statistical factorial method
5) Rheology of paste model

However, all this method still cannot fully meet requirement for effective cost production, sustainability and not applicable to utilize for variable of alternative raw material which subject to the requirement while in fresh and hardened state of SCC [44].

In general, through previous research the target compressive strength for SCC normally range from 20 to 100 MPa for 28 days. Average result from previous research achieved strength at 40 MPa [46].Some researcher also study SCC focus on High Performance Concrete which mean the compressive strength more than 100 MPa [47], [48].

As a conclusion,SCC have a flexibility and no unique mix design as long as it can perform to real application, practical, economy and obtaining good quality during it fresh and hardened state. Overall performances are base on raw materials used in the mix design.

3.0 MATERIALS IN SCC

SCC is mainly emphasized on filling ability, passing ability and segregation resistance during fresh state by its own weight. Therefore, there were not much different in term of materials appreciation in mix design principle between SCC and ordinary concrete as known as Normal Vibrated Concrete (NVC). However, the mix design for SCC is still under research as mentioned earlier.

Fresh state performances of SCC are more influence by filler materials. Filler materials also can influence the performance of SCC in short term or long term. For example, FA, LP, SF and GGBS have some positive and negative impact to SCC in term of amount water content usage, flow ability, segregation resistance and hydration effect [43]. Therefore continual study in SCC is still in progress all around the world. The researchers are looking into many aspect and alternative to develop and establish their finding in SCC development.

3.1 Basic and Common Materials in SCC

The common material in SCC are cement, course aggregate, sand, filler or powder (LP, FA, SF, GBFS), super plasticizer (SP), viscocity agent (VA) and water.

Typical content of cement is between 350 to 450 kg/m^3. Cement content more than 500 kg/m^3 will have a side effect on shrinkage. Cement content less than 350 kg/m^3 should incorporate with fine filler material such as Fly Ah, Bottom Ash, Limestone Powder and any other suitable fine material less than 0.125 mm. Amount of fine filler will significantly help on performance of SCC during fresh state evaluation [3], [43].

Till today, SCC still have flexibility to be developed as long as it can perform to real application, practical to implement on site, economical in production and sustainable for environmental [44]. Therefore, some of the common fine material will be discussed to provide general idea on the effect of the performance in SCC.

3.1.1 Limestone Powder (LP)

Limestone powder is a by product obtain from quarry activity (stone crusher quarry). LP has significantly become an issue to quarries industry to dispose this material. In long term it will generated environmental pollution and create a side effect on health hazards due to huge amount of stockpile. Therefore, utilizing LP in SCC is one of the solutions to the above mentioned.

Base on investigation done by a group of research from India, they have using a high quality LP as replacement material for cement. It was shown that, the compressive strength achieved between 40 MPa to 45 MPa by the replacement of LP between 2 to 10 % with combination of SF (1-6%), QD (5-45%) and Clinker (2-20%) which was totally without cement content[9].

In another research, the used of LP can improve viscosity with combination of other minerals which are Silica Fume, Pozzolan, FA and cement. Increasing amount of LP shown positive result for viscosity effect [8][49][14].In general, combination of LP and FA can help to increase the strength of SCC [50].

Amount of LP can be fix or calculate by using unit weight or unit volume. In USA, a research about combination FA and LP have been conducted. They have fixed the LP amount between 15% to 25% by unit weight of cement contents [50].

As the conclusion, utilizing of LP was very good alternative to reduce environmental problem. Therefore study on the influence of LP on durability and performance either as stand alone and combination with other materials should be supported and extended in the future for the quality improvement.

3.1.2 Fly Ash (FA)

FA also known as a Pozolanic materials which can increase compressive strength proportional to time increase. It can increase cohesion and reduce sensitivity to change in water content. FA can be divided into two categories that is class F and class C. However, amount of FA should be control in order to avoid resistant flow. Which means, high amount of FA will increase cohesive and make SCC difficult to flow [43].

FA normally used to reduce or replace amount of cement used in SCC. Some researchers have used 50% to 70% FA as cement replacement material. However, increase amount of FA will reduce compressive strength. The compressive strength was reduce due to increment of porosity in SCC created by FA in SCC [51].

On the other hands, utilizing FA (15, 25 & 35%) proven to create good performance in workability through slump flow test, T_{50} time test, V Funnel test and L Box test [12].

As the conclusion, the amount of FA should be controlled and alternative combination between other various supplementary material can help to improve the performance of SCC[52].

3.1.3 Granulated Blast Furnace Slag (GBFS)

GBFS is a ground granular material formed when molten blast furnace slag is quickly cooled. Production amount of GBFS are 530 million tonsper year in worldwide and 60 million tons are generated in China. Normally GBFS are used for cement replacement [38].

GBFS can be used for addition or replacement material in SCC.Now days, researchers not only using GGBS alone but also using combination of GBFS with other material such as FA and LP. Combination of FA and GGBS has unique and distinctive effect on the properties of the SCC. It can improved the rheological properties and increase the setting times of cement pastes in SCC [47]. GBFS can also improved resistant again sulphate attack, workability and compressive strength [12].

As conclusion, GBFS is suitable for filler replacement material in SCC. It can help to improve the workability, minimize segregation and reduce bleeding effect with the increasing amount of GBFS [53].

3.2 Alternative Waste Materials

There are many abundant waste materials that generated from by product industry and construction industry and this waste contributed to environmental problem. Therefore, researchers may have opportunity on utilizing waste materials to be used as filler or powder in SCC for replacement material or additional material. For example, some of waste materials that have been utilized in SCC are Quarry Dust (QD), Dolomite Powder (DP), Rubble Powder (RP), Recycled Aggregate, Marble Powder (MP), Cement Klin Dust (CKD), Roof Tiles, Rise Husk Ash (RHA) and Palm Oil Clinker (POC). Some of the alternative material will be discussed to provide general idea on the effect of the waste material applied in SCC. In this summary, utilizing of MP, DP, RAP and RHA will be discussed in order to provide some general view on the effect of substitution or replacement to proportion in SCC.

3.2.1 Marble Powder (MP)

The marble has been commonly used as a building material since ancient times. Disposal of the waste materials from the marble industry, consisting of very fine powders, is one of the environmental problems worldwide today. Sometimes, waste marble from construction site during construction and demolition also contribute to environmental dispose problem. Therefore, these waste materials have potential to be utilized in production of SCC for filler and fine material replacement.

From Table 1, utilizing waste from marble industry has been conducted in Turkey since 2009, 2011, 2012 and 2014.Increasing amount of MP in SCC will decrease the compressive strength. These results are base on volume of powder between cement and MP. The higher compressive strength (73.8 MPa) are 500 kg/m^3 cement and 50 kg/m^3 MP. While the lowest compressive strength (26.7 MPa) are 300 kg/m^{3}cement and 500 kg/m^3 MP. A slump flow design for two cases is 55-65 mm and 66-75 mm. However, this mix design only suitable for without reinforced or slightly reinforced concrete and also for pump mix design[6].

Utilizing 10, 20 and 30% of MP base on fix volume of powder content (MP and cement) have a good compressive strength on 28 days by achieving 86.3 MPa, 82.2 MPa and 80.6 MPa. It was shown that increasing amount of MP would reduce the compressive strength of SCC. While, increase amount of MP also reduce slump flow values but having better sulphate resistance attack due to pore size refinement compare with other mineral admixtures such as LP, BF and GBFS [12].

Gesogla and Uysal are both agree in effect of increasing amount of MP will contribute to decrease of slump flow value. The slump flow diameter will decreased proportional to increasing of V Funnel and slump flow times[12], [14]. Utilizing MP resulted in an increase amount of super plasticizer in order to maintain acceptable value for slump flow.

3.2.2 Dolomite Powder (DP)

DP is a by product taking from an industrial stone crushing plant. The source of dolomite is depending on geological mapping and expected to vary over the time. Dolomite powder is characterized as non-pozolanic material and suitable as a filler material in SCC. Increase amount of DP alone will decrease compressive strength in SCC. However, combination of DP with FA at 25, 50 and 75% at constant amount of 290 kg/m^3 shown value of compressive strength achieved over 30 MPa [10]. As conclusion, DP alone can be used as a filler material but not as pozolanic material in SCC. It could contribute to reduce environmental pollution and part of producing sustainable product through utilizing DP in mix proportion in SCC.

3.2.3 Crump Rubber (CR)

In Turkey, crump rubber (waste from used tires) is one of recycled material that has been used to replace fine aggregate in SCC. Utilizing CR from5%, 15% and 25% with proportion of FA at 20%, 40%& 60% (cement substitution) in volumetric ratio resulted compressive strength range from 16MPa to 86MPa at 20 and 90 days. However, this combination shown that increasing of CR will also reduce the compressive strength. Increasing amount of CR will created high porosity as resulted in high water absorption, which is not good for Chloride ion permeability test [54].

3.2.4 Recycled Aggregate (RA)

Recycled aggregate is also one of a major waste in construction site. It was produce either during construction or during demolition works. Therefore is good to utilize and convert this material into sustainable product in order to reduce it impact to the environmental issues. One of the alternatives is to use it as replacement material as a natural aggregate or as a crushed fine material. However, uncontrolled supply of RA will create a draw back such as lower density, higher water absorption capacity and unsystematic angularity. Beside that, the quality of RA also effected from the original sources of supply chain [55].

A proper supply chain should be established in order to control the quality of RA product. In Italy, recycled aggregate can be supply by an industrial crushing plant that using rubble from building demolition. They have conducted a proper quality checks in order to avoid hazardous materials such as asbestos or chalk in production of RAP. The gradation of RAP are base on sizes from 6 mm and 15 mm maximum with quality clean control and sieve process [11]. Therefore the quality of RA can be consistence and monitor the grading before supply to other industry for recycled purpose.

Increasing amount of RAP in SCC also reduce the value of compressive strength and increase water absorption rate. This was similar to the effect of other recycled materials such as MP and DP[35], [56].

3.2.5 Rice Husk Ash (RHA)

RHA is one of recycled material that can be used to improve the properties of concrete. It can be used either in blended (powder) or unblended condition. Previous researches indicated that RHA suitable for supplementary cementitious material in concrete due to it highly pozolanic condition [57].

At early stage, RHA content decrease compressive strength at 3 days and 7 days but increase compressive strength at 28 days according to mix design strength. This is due to pozolanic reaction that has refine porosity effect at the early stage. Somehow, utilizing of RHA with combination of LS have benefit in producing high strength of concrete[40]. Therefore, utilizing RHA as sustainable product have shown beneficial to concrete industry and also benefit to reduce environmental problem. This will indirectly contribute to generate economic value to rice husk demand in the future.

4.0 CONCLUSION

The development of SCC have a flexibility and no unique mix design as long as it can perform to real application, practical and economy during it fresh and hardened state. This paper has summarized the development of SCC in Table 1. Through this review, the following conclusion can be made,

1) There are many alternative materials especially recycled product and by product can be utilized in mix design for SCC. This paper aim only on 5 types of waste materials which are MP, DP, CR, RA and RHA that related to SCC development.
2) Amount of recycled or alternative materials utilize in SCC should be control to avoid reduction in compressive strength. Generally, increasing amount of waste materials such as MP, DP, CR and RA will decrease the compressive strength of SCC.
3) Utilizing of MP, DP, CR and RA significantly show an improvement of workability but cannot ensure to have a good result in compressive strength. Therefore, the fresh state and hardened state of SCC should be inline together.
4) RHA react as pozolanic material which can be used as cementitious replacement. It is also performance better in compressive strength with combination amount of LS.
5) Condition or original sources of waste material have must effect on the quality of production sustainable product. For example, grade of concrete to produce RA, temperature of burning RH, geological area of dolomite and expired date of recycled tires.

In overall, based on Table 1, this paper confirmed that the development of SCC is stil can be explore by utilizing waste material to produce sustainable SCC and reduce environment problem. Therefore, the make used of by product and recycled materials are taking place in SCC that can be part of design efficiency, practicable and economical value to be explored. A lot of improvement can be adept and improvised for better future concrete technology development.

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