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Research paper



Experimental Investigation on Self-Compacting Concrete with Waste Carbon Black

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Abstract

One of the vital aspects in designing self-compacting concrete (SCC) is the amount and type of filler with respect to cement and water. These have a great impact not only on fresh SCC properties (segregation, filling, fluidity, etc.) but also on its hardened properties. In this experimental study, an attempt was conducted to diminish the pores occurrence in SCC by using carbon black as a filler, which is a waste from the rubber industry. The experimental work investigates the SCC properties when crusher dust filler from the aggregate plant was partially replaced by waste carbon black. SCC mixes of two carbon black replacement ratios (2.5% and 5%) were studied to reveal its effect on the fresh and hardened properties, through various tests. The fresh properties were investigated by means of slump flow (t_{500}), J-ring and L-box. The compressive and splitting tensile strengths tests were implemented along with the mix density evaluation to characterize the hardened properties of SCC with black carbon. It has been found that the carbon black has a useful role for the fresh properties of SCC. Indeed, the carbon black provides superior performance for the compressive strength development than crusher dust. In contrast, it slightly worsened SCC splitting tensile strength.

Keywords: *Carbon black;, crusher dust; Mechanical properties; SCC.*

1. Introduction

Self-compacting concrete (SCC) was invented owing to the steep decline in the skilled worker in Japan in the 1980s (Okamura et al., 2000). SCC characteristics are affected by the powder materials content (cementitious materials and filler), the water to binder ratio, and the superplasticizers use (Elyamany et al., 2014). Currently, for various reasons, the SCC construction industry could be considered as unsustainable. Primarily, massive quantities of virgin materials were consumed, which could endure for the next generations. Moreover, Portland cement is the main binder in SCC in which its production considers as the main supplier to the emissions of greenhouse gas that are implicated in climate change and global warming (Long et al., 2015). Being a useful material, the presence of inherent flaws in SCC found to be the main issue since ever it was revealed. Pores, especially the small cracks (microcracks), in turn, appeal fluids that cause countless ill belongings such as lower compressive strength, lower chloride ion resistance, acid intrusion, and freezing and thawing etc (Sri Kalyana et al., 2015). By considering this issue, researchers have focused on several additives. One of the well-known additives is the carbon black, which is used to lessen the pores present generally in concrete due to its extremely small particle size. It is a by-product black powder from the rubber industry produced by the incomplete combustion of heavy petroleum products such as coal tar and a small amount from vegetable oil (Priya and Pandeeswari, 2016). It is of colloidal particles form whose particle size range from 8 to 100 nanometers. Its formation in huge amount creates problems in disposal and when it gets mixed with soil, it reduces its properties. It also contaminates the water which leads to water pollution.

The positive influence that carbon black can have on concrete was well documented, generally through numerous studies. Chitra et al., (2014) studied the addition of carbon black in a variety of ratios (0%, 2%, 5%, 8%, 12% and 15%) to conventional concrete. They found that carbon black beyond 8% causes a reduction in the performance in comparison with specimens of 12% and 15%. They were also stated that adding carbon black as a filler by up to 5% found to be effective in concrete. Furthermore, the addition of 8% carbon black in the concrete shows excellent closure of pores and for water absorption. Nagavkar (2017) demonstrated the effect of partial replacement of several types of additives with cement on the properties of concrete. One of these additives was the carbon black in varied replacement levels (0%, 3%, 5%, 7%, 9% and 12%). It was observed that the use of carbon black can enhance the mechanical properties of concrete. Furthermore, it can help in the producing more economical and eco-friendly concrete. Jeyashree and Chitra (2017) conducted a study on the compressive strength, splitting tensile strength, flexural strength, uniformity, and surface hardness of concrete specimens containing several carbon black percentages. They concluded that the optimum carbon black percentage lies within (5-8) %, which can effectively enhance the properties of concrete. Similar results have been stated by (Priya and Pandeeswari, 2016). Ahmedzade and Geckil (2007) investigated the carbon black effect on the electrical and mechanical properties of an asphalt mixture. Marshal stability, indirect tensile modulus, creep stiffness and indirect tensile strength tests were performed. Results showed that carbon black enhances both mechanical and electrical conductivity of asphalt mixture. Kharita et al., (2009) studied the effect of adding carbon black powder on the properties of hematite radiation shielding of concrete. It was concluded that adding 6% carbon black powder (by weight) to concrete can increase its strength by about 15%.

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However, such addition caused a decrease in the shielding characteristics for both gamma and neutrons. In their study, Goldman and Bentur (1993) substituted silica fumes by carbon black as an alternate micro filler. The result indicated that carbon black was effective in modifying basic concrete matrix strength to an extent similar to silica fumes. Masadeh (2015) examined the steel bars corrosion after adding carbon black to a concrete mix. This was accomplished by inserting steel bars in different concrete with different carbon black percentages. Specimens were immersed in 3.5% chloride solution for 180 days. It was observed that the corrosion rate decreases as the carbon black increases due to the increase in concrete density.

From the above, a detailed literature has been carried out and revealed that carbon black can successfully contribute to an improvement in the properties of normal concrete. However, in the all published work, the role of carbon black on SCC properties does not appear to have been investigated (to the best of our knowledge). Thus, the main aim of the current work is to experimentally investigate the influence of cement substitution by carbon black on the fresh and hardened properties of SCC. The crusher dust filler, which has been used as a filler were substituted by two substitution percentages of carbon black; 2.5 and 5%. According to the obtained results, the optimal substitution percentage of carbon black was also determined.

2. Materials

2.1. Cement

The cement used for this research work was a sulfate resisting Portland cement locally available and it is known commercially as Al-.jesser

2.2. Sand

Al-Ekhaider sand of (4.75 mm) maximum size is used as fine aggregate in the SCC mixes and it conformed to the standard specification [13]. It was air dried for 72 hours in the lab to reduce the existing moisture in it. The sand was sharp and clean, free from loam, dirt, and clay or any organic matters.

2.3. Coarse Aggregate

The coarse aggregate used in the SCC is of maximum size equal to 20 mm and it conformed to the standard specification [13].

2.4. Crusher dust

Crusher dust is a white powder produced when breaking rocks and large gravel. It is added to SCC mix to increase the viscosity to avoid segregation.

2.5. Carbon black

It is practically a pure elemental carbon of colloidal particles form, which are formed by thermal decomposition or incomplete combustion of liquid or gaseous hydrocarbons under controlled circumstances. It is a finely black divided powder or pellet that is waste from the industry of rubber, finds in the. Due to its difficult disposal, these rubber wastes are normally dumped into earth producing and contamination for soil and water table. Utilization this carbon black waste as filler in concrete can significantly reduce the pollution and contamination issue. The specific gravity of carbon black was measured by density bottle approach and it was equal to 1.33 (Chitra et al., 2014).



Plate 1: Carbon black in the powder form

2.6. Superplasticizer-Sika 5930

The use of a superplasticizer can effectively provide high deformability by dispersing the flocculated cement particles causing a reduction in the attractive forces among these particles and keeping a low water to powder ratio. Superplasticizer can be suitable for concrete production and can offer excellent flowability and significant water reduction resulting in an optimal cohesion and superior SCC behaviour.

2.7. Microwave

Heating by microwave is an extremely efficient method for diverse thermal processes. In comparison to conventional heatingprocessing methods, microwave heating can provide rapid heating rates, save energy and reduce processing times, deep microwave energy penetration. This can permit efficient heat generation without directly contacting the work-piece, clean heating processes, particular and immediate electronic control, and no secondary waste. Energy processes by microwave for drying, curing and heating have been established for plentiful laboratory-scale research and, in some cases, have been commercialized. In this regard, microwave energy use should be theoretically beneficial in cement and concrete materials processing (e.g., hydraulic Portland cement, water, and aggregate). These materials display outstanding dielectric properties resulting in absorbing microwave energy efficiently and convert it instantaneously into heat (Elakkiya et al., 2018). For all the above feature, it has been decided to utilize microwave treatment by two various times (5 and 10 minutes) next to conventual water curing.

3. Mix proportioning

The task of mix design is to optimize the SCC ingredients to get the best possible productivity in terms of fresh and hardened performance. This can be done by optimizing the compositions by estimating various SCC components with different combinations of ingredients and then to select the optimum variants of these mixes by associating their fresh properties, as well as their mechanical properties. Diverse methods existed for the designing of SCC compositions that are constructed upon various concepts (Shi et al., 2015) taking into consideration the characteristics of ingredients and the wanted properties of the SCC. The ingredients characteristics are either measured or determined by empirical formulas. The mix design method proposed in this paper was the one developed in (Abo Dhaheer et al., 2016) (Alyhya et al., 2016). SCC mixes, which contained various volumetric paste to solid ratios were prepared using the design charts proposed in the above-mentioned method (see Table 1). The mix was widely verified in the fresh state by means of slump cone, L-box, and J-ring. SCC, in its simplest form, is a paste and aggregates mix. The paste, composed of cementitious materials, filler and water that coat the surface of the coarse and fine aggregates.

Table 1: Mix proportion for SCC, kg/m^3

Mix design-nation	Ce-ment	Crusher dust	Car-bon black	Fine ag-gre-gate	Coarse aggre-gate	w/c	Su-per-plasti-cizer
Mix 1*	410	101	-	824	884	0.4	0.08
Mix 2**		98.475	2.525				0.12
Mix 3***		95.95	5.05				0.15

** Control mix;*
*** SCC mix with 2.5% carbon black;*
**** SCC mix with 5% carbon black;*

3.1 Mix preparation and specimens casting

The SCC was produced by using pan mixture. Prior to the starting of the rotation mixer, add the coarse aggregate, some of the mixing water, and the admixture solution, when required. Formerly, add the cement, fine aggregate, and water. These ingredients may be added to the mixer prior to permitting it to turn a few revolutions following the adding of coarse aggregate and some water. Mix the ingredients in the mixer for 3 min followed by a 3-min rest and by a 2-min as a final mixing. Cover the opening of the mixer to avoid evaporation during the rest period. Take precautions for mortar compensate that retained by the mixer in order to correctly proportioned the discharged batch. Slump flow, J-ring and L- box test were carried out on the fresh SCC to determine the passing ability, flow and filling abilities in accordance with the specifications (EFNARC Guidelines, 2005). The fresh concrete was poured into cubic (100×100×100 mm) and cylindrical (100×200 mm) moulds and left to harden for 24 hours. After the hardening of specimens, they were taken out of the mould and kept in water till the date of the test. The cubes and cylinders were immersed for the duration of 7, 14 and 28 days. Prior testing, all specimens treated for various times (5 and 10 minutes) in a domestic microwave for extra curing. The cubes were taken out after the specified duration in which they were weighed and tested for density, compressive strength and splitting tensile strength tests.

4. Results and discussions

The results from the laboratory tests for the effect of using carbon black and microwave on the properties of fresh and hardened SCC were given below.

4.1 Fresh properties

The different tests results carried out on the fresh SCC are given in Table 2 and illustrated in Figure 1.

Table 2: Fresh properties of SCC mixes

Mix design-nation	Slump flow		J-ring		L-box		
	Spread Diameter, mm	t500, sec	Spread Diameter, mm	t500-j ring, sec	t200, sec	t400, sec	H1/H2
Mix 1	650	5.0	630	6.5	3.4	6.3	0.86
Mix 2	640	5.5	625	7.0	3.5	6.7	0.84
Mix 3	630	5.7	620	6.8	3.9	6.6	0.80

According to the EFNARC guidelines for SCC slump flow test, all mixes fall within the range of acceptable values. The results above show increasing flow time with increasing per cent replacement levels of carbon black. All replacement levels can be seen to fall within the recommended EFNARC standards and all fall into the category SF1 (≤ 8 sec). Hence, they all satisfy the slump and J-ring requirements.



Fig. 1: Fresh SCC test

It can be also noticed that increasing the carbon black percentage causing a reduction in the workability of the SCC. The results also showed decreasing blocking ratio with the increase in carbon black replacement levels. According to the EFNARC guidelines, both replacement levels have satisfied the limits of the blocking ratios ($H_2/H_1 \geq 0.8$). This indicates that increasing the per cent replacement levels can reduce the filling ability of the fresh SCC resulting in lower workability. Nevertheless, according to EFNARC guidelines (2005), the ratios of blocking that are falling within 0.6-1.0 are considered to be acceptable. Therefore, it can be concluded that all black carbon replacement levels displayed satisfactory results based on the above-stated conditions.

4.2 Hardened properties

4.2.1 Compressive strength

The 3, 7 and 28 days compressive strengths for various SCC mixes (i.e. SCC mixes with the various replacement of carbon black and various microwaving times) are tabulated in Tables 3-5. All data presented here are the mean figures of three experimental results. As expected, the compressive strength in all mixes increases with age due to the conventional hydration process. Table 3 and Fig. 2 below provide data for the relationship between the compressive strength in MPa and age in days for Mix 1.

Table 3: Compressive Strength in MPa for Mix 1

Age(day)	0 min	5 min	10 min
3	17.6	18.2	18.5
7	22.9	25.7	26.6
28	32.9	34.9	30.3

Figure 2 shows the results of the SCC compressive strength at 3, 7 and 28 days that are additionally cured by microwave for various times. Results were compared with those specimens that were only watery cured (i.e. specimens that tested without microwave treatment). The figure indicates that SCC specimens treated for a longer time in the microwave (i.e. 10 minutes) provide higher results for 3 and 7 days age strength. Further examination of Figure 2 illustrates that the 10 minutes microwaving time was not adequate to provide higher strength at a later age of 28 days (i.e. higher cement hydration products). This is may be due to the fact that the 5 minutes microwaving time led to an early overheating and distinctly significant improvement in strength.

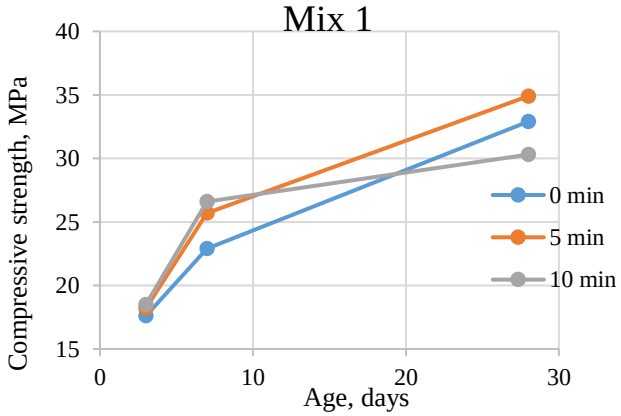


Fig. 2: Compressive strength and age relationship

Table 4 below gives the results of the compressive strength in MPa for Mix 2. Fig. 3 shows the relative strength gain of SCC specimens in ages of 3, 7 and 28 days for different microwave curing periods. The first glance at that figure can clearly state that the additional microwave curing for various times allows the concrete to go faster from the plastic state to the hardened state (i.e. faster gain of strength over time). Indeed, the strength gain in the early ages (3-days) occurs at a faster rate and it slows down at the later ages (7 days). This contribution to strength is may be due to the densification in the SCC mix due to the use of carbon black. Moreover, the utilization of the microwave causing an increase in the hydration process, which led to the collapse of the pores system and concrete densification.

Table 4: Compressive Strength in MPa for Mix 2

Age(day)	0 min	5 min	10 min
3	19.8	17.3	16.1
7	23.5	24.1	25.7
28	26.9	30.2	31.8

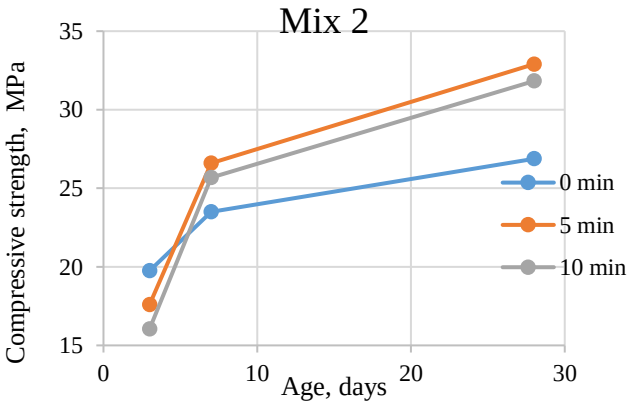


Fig. 3: Compressive strength and age relationship

On the other hand, Table 5 and Fig. 4 demonstrate the compressive strength of SCC specimens for Mix 3.

Table 5: Compressive Strength in MPa for Mix 3

Age(day)	0 min	5 min	10 min
3	15.9	20.9	22.4
7	23.0	29.8	30.6
28	33.3	33.7	37.8

It is clear from the figure that at all the studied ages (3, 7 and 28 days), the strength development was higher in specimens subjected to various microwaving times in comparison with those cured by water only. For instance, the specimens subjected to a microwave of five minutes achieved a 3-day compressive strength of 20.9 MPa in comparison with only 15.9 MPa for those cured by water only. Indeed, the specimens that are cured additionally by microwave of five minutes has a 7-days compressive strength of 29.8 MPa compared to only 23 MPa for those watery cured. Obviously, the increase in the compressive strength could be a consequence to the further hydration of the un-hydrated cement grains resulting from the effect of internal autoclaving, in addition to the ‘’crossover effect’’ phenomenon, which is a maturity concept that defines the combined influence of age and temperature on strength development. The higher hydration products, which produce CSH could be deposited in the formed pores resulting from evaporation of water causing a bridging of the existed pores. Besides, the strength enhancement could also be partially due to the enriched hydrated cement during the evaporation of the free water, which improves the forces of Van der Waal as the cement gel layers become closer to each other. It is worth to mention that these results are in a wide-ranging agreement with those mentioned in the literature.

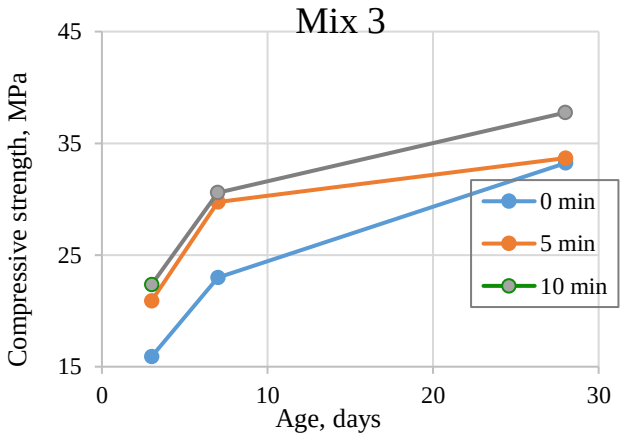


Fig. 4: Compressive strength and age relationship

4.2.2 Splitting tensile strength

A tensile failure occurs rather than a compressive one as the load application areas are larger than the compression area. Thin plywood bearing strips were utilized in order to apply the load uniformly along the length of the cylinder. The maximum load is divided by the appropriate geometrical factors to obtain the splitting tensile. Results of the splitting tensile strength of specimens cured in various microwaving times are tabulated and illustrated in Tables 6-8 and Figures 5-7.

Table 6: Splitting tensile strength versus age for Mix 1

Age(day)	0 min	5 min	10 min
3	3.0	2.8	2.3
7	3.3	3.1	2.8
28	4.5	4.1	3.4

It is obvious from these figures that the splitting tensile strength found to be affected by additional microwaving curing. From the tests results, it can be noticed that the impact on the pores structure increases as the microwaving time increases. For instance, if the microwaving time becomes 5 minutes after traditional water curing

till the date of test, the splitting tensile strengths in ages of 3 and 7 days become equal to 2.8 MPa and 3.1 MPa respectively in comparison to that of specimens treated for 0 minutes (they were just equal to 3.0 and 3.3 MPa receptively). It is worth to mention that the splitting tensile strength continues to decrease despite continuing the hydration process of cement. On the other hand, specimens cured additionally by microwave seemed to have a similar decrease in the splitting tensile strength profile in all the studied ages. It is worth to mention that the main reason behind the decrease in the splitting tensile strength is that additional curing by microwave causes fast curing and consequently could control the pore size distribution especially the mesopores volume. Indeed, such a fast curing process occurred by the proposed additional treatment regime may cause a non-uniform distribution of the hydration product resulting in a microstructure with a high volume of pores. Another potential reason for such splitting tensile strength decrease in the presence of the unreacted cement particles that are been surrounded by the dense hydrated phases causing the stoppage of further hydration.

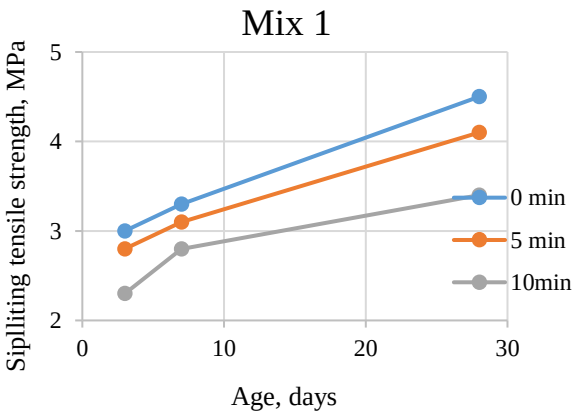


Fig. 5: Splitting tensile strength versus age for various microwaving times

Table 7: Splitting tensile strength versus age for Mix 2

Age(day)	0 min	5 min	10 min
3	2.8	2.5	2.2
7	3.5	3.1	2.7
28	3.9	3.4	2.9

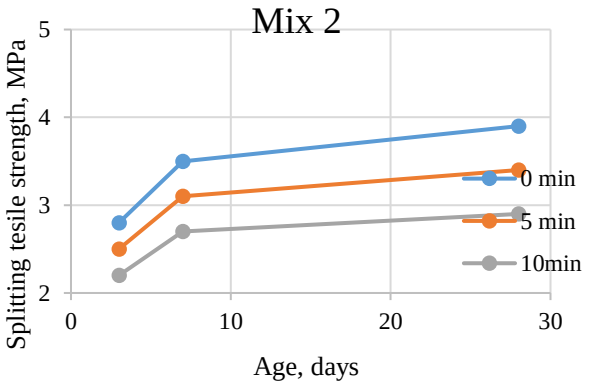


Fig. 6: Splitting tensile strength versus age for various microwaving times

Table 8: Splitting tensile strength versus age for Mix 3

Age(days)	0 min	5 min	10 min
3	2.6	2.3	1.9
7	2.9	2.6	2.3
28	3.1	2.8	2.6

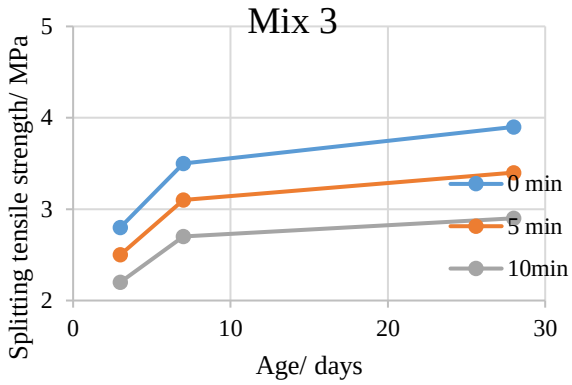


Fig. 7: Splitting tensile strength versus age for various microwaving times

4.2.3. Density

The density can provide an indication of how loosely or tightly the molecules been packed in the network system. The network packing variance among SCC mixes that have various carbon black ratios can be examined through the density test. Figure 7 illustrates the average density of the SCC mixes that are treated with microwave. It can be revealed that specimens with higher replacement level as well as those cured by microwave for a further time gave higher densities in comparison with those specimens without carbon black and/or microwave treatment. This implies that the network structure of Mix 1 was less compact than Mix 2 and Mix 3.

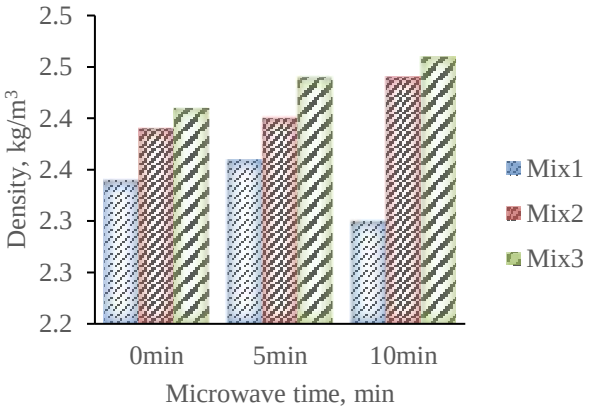


Fig. 7: The density of various SCC mixes

5. Conclusions

The following conclusions can be drawn based on the results from the present study:

1. It was observed that increasing the carbon black ratio from 2.5% to 5% can lead to an effective increase in the compressive strength results with age. Thus, carbon black proves as an excellent additive from which higher compressive strength can be obtained.
2. Using carbon black led to an increase in the splitting strength for SCC with age.
3. It can be also noted from the results that the using ratio of carbon black and increase this ratio from (2.5% to 5%) led to increasing the density of the hardened SCC. Therefore, carbon black proves as good filler and fills the pores.
4. The effect of the microwave when it uses as a curing technique was clear in increasing the mechanical properties of SCC.

5. Furthermore, the using of the microwave in curing led to increasing the density of SCC with the time of curing.
6. The optimum time of the curing by microwave was 5 min.
7. The optimum ratio of carbon black was 5%.

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