UTILIZATION OF SODA AND BEER WASTES IN CEMENTITIOUS SYSTEMS

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ABSTRACT

UTILIZATION OF SODA AND BEER WASTES IN CEMENTITIOUS SYSTEMS

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To maintain the sustainability of cement and concrete production, there is a trend to use wastes in their production. Soda waste, generated by soda ash production process, and beer waste, generated by beer filtration process, are two locally produced wastes in Turkey and many other countries. The nature of these wastes, mostly their fineness, makes them possible to be used in concrete production, especially as a viscosity modifying agent in the self consolidating type of concrete.

In this study, the addition of soda and beer wastes to self consolidating mortar (SCM) and self consolidating concrete (SCC), without any treatment but drying, and its effect on their properties were investigated. Mortar and concrete mixes various amounts. Tests like slump flow, V-Funnel and L-Box for determining the fresh properties, and compressive strength for the hardened properties of the mixtures were carried out to examine the effects of these wastes on the properties of SCM and SCC.

The tests revealed that soda waste takes no role in the strength development of the mixes. However, it is possible to use this waste as aggregate replacement to improve the workability and flowability properties of SCM and SCC. The use of beer waste showed contradictive results. A special treatment for this waste before using it in concrete might be required.

Keywords: Soda waste, beer waste, self consolidating mortar (SCM), self consolidating concrete (SCC).

ÖZ

SODA VE BİRA ATIĞININ ÇİMENTOLU SİSTEMLERDE KULLANIMI

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Çimento ve beton üretiminin sürdürülebilirliğini sağlamak amacıyla, üretimde atık kullanımı eğilimi oluşmaktadır. Soda külü üretim işlemiyle oluşan soda atığı ve bira filtrasyon işlemiyle oluşan bira atığı Türkiye'de ve birçok farklı ülkede yerel olarak ortaya çıkan atıklardır. Bu atıkların nitelikleri, özellikle de incelikleri, beton üretiminde özellikle de kendiliğinden yerleşen betonlar için viskozite düzenleyici katkı olarak kullanılmasını mümkün kılmaktadır.

Bu çalışmada, kurutma dışında hiçbir işlem görmemiş soda ve bira atığının kendiliğinden yerleşen harç (KYH) ve kendiliğinden yerleşen betona (KYB) eklenmeleri ve kendiliğinden yerleşen harç ve kendiliğinden yereleşen betonların özellikleri üzerine etkileri incelenmiştir. Harç ve beton numuneleri, bu iki atığın, çimento veya agrega yerine çeşitli oranlarda ikame edimesi suretiyle hazırlanmıştır. Atıkların KYB'de kullanımını sınamak amacıyla taze özelliklerin belirlenmesi için slump flow, V kutusu ve L kutusu ve sertleşmiş durumdaki özelliklerin belirlenmesi için basınç dayanımı gibi testler uygulanmıştır.

Test sonuçları, soda atığının betonun basınç dayanımı kazanımında hiçbir rolü olmadığını göstermiştir. Ancak, bu atığın KYH ve KYB'nin işlenebilirlik ve akışkanlık özelliklerinin geliştirilmesi amacıyla agrega ikamesi olarak kullanılması mümkündür. Bira atığı kullanımı çelişkili sonuçlar göstermiştir. Bu atığın, betonda kullanımı öncesinde, özel bir işlemden geçirilmesi gerekebilir.

Anahtar kelimeler: Soda atığı, bira atığı, kendiliğinden yerleşen harç (KYH), kendiliğinden yerleşen beton (KYB).

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LIST OF ABBREVIATIONS

ACI:	American Concrete Institute.
AE:	Air Entraining agent.
ASTM:	American Society for Testing Materials.
EFNARC:	The European Federation of Specialist Construction Chemicals and Concrete Systems.
EN:	European Norms.
SCC:	Self Consolidating Concrete.
SCM:	Self Consolidating Mortar.
SP:	Superplasticizer.
TS:	Turkish Standards.

CHAPTER 1

INTRODUCTION

1.1 General

In the last century concrete has become a daily used material for human beings. With an estimated annual consumption of 7.9 billion m^3 [U.S. Geological Survey, 2009], concrete is considered the most widely used construction material in the world. The main aim of using concrete is to produce strong and durable structures while maintaining an economical side. With the growing increase of this production, a wide range of problems is created, like the consumption of natural mineral resources such as the raw materials and fuel used in cement production, the pollution generated from the cement plants, or the land used for quarries that need to be restored at the end. Hence, the sustainability of cement and concrete has become a major concern these days. By using alternative fuels and raw materials, some of these sustainability issues can be solved.

The growth in industrial activities leads to an increase in the amount of waste production along with a rise in the concerns about the negative effects of these wastes on the environment. This thing has put the waste disposing on one of the top priorities for communities and industries. Although land filling and recycling are the most common waste disposal methods, manufacturers now are trying to use the wastes as raw materials or additives in other products. The nature of production process of cement and concrete provides big opportunities to use wastes in this process. In cement manufacture, the crushers, the mills and the kiln's enormous temperature can almost overcome any waste, while the concept of concrete of binding filler materials makes it quiet possible to use wastes in its production. Of course, the main concern or condition in that uses is to preserve the quality of the products.

There are many wastes used in the field of cement and concrete as substitute fuel or raw material, cement replacement or filler. The use of some of these wastes can be really economical for the production of cement and concrete and even sometimes very beneficial at improving the properties of concrete. Using tires as substitute fuel and ceramic tiles as raw material in cement production, fly ash, silica fume and granulated blast furnace slag as cement replacement are only few examples of wastes used in cement and concrete production, and still a lot of investigations and research are performed to evaluate the usability of many other wastes.

Soda waste, the waste generated by soda ash production process, and beer waste, the waste generated by beer filtration process, are two locally produced wastes in Turkey and many other countries. These wastes create disposal problems for the manufacturers who have no other choice except for land filling them. The nature of these wastes, their fineness at most, makes their use in concrete production quite possible, especially as a viscosity modifying agent in the self consolidating concrete (SCC). Adding soda and beer wastes to SCC might improve its properties or at least be a disposing solution. In this study, this possibility is evaluated and the fresh and hardened properties of SCC are determined.

1.2 Objective and scope

The objective of this study is to investigate the usability of soda and beer wastes in cementitious systems as viscosity modifying agents in SCC. To accomplish this, mortar and concrete mixtures in which the soda and beer wastes were used as cement or aggregate replacement with various ratios, were prepared. Tests like slump flow, V-Funnel and L-Box for determining the fresh properties, and compressive strength for the hardened properties of the mixtures were carried out to investigate the effects of using these wastes in SCC.

To fulfill this objective, this thesis involves five chapters including this one. In Chapter 2, a literature review is presented about using wastes in cement and concrete. The origin of soda and beer wastes is also presented along with their possible uses. At the end of this chapter, a brief background of SCC is given.

Chapter 3 contains the experimental procedure. Details of the experimental procedures to determine the properties of the materials and the test methods used are explained in this chapter. The experimental program along with the mixture ratios are also provided in this chapter.

The subject of Chapter 4 is the results of the tests performed, where the effects of using soda and beer wastes on the fresh and hardened properties of self consolidating mortar and concrete are presented and discussed.

Finally, the summary of this thesis and the conclusions along with recommendations for future work are given in Chapter 5.

CHAPTER 2

LITERATURE REVIEW AND BACKGROUND

2.1 General

Waste generation is almost inevitable during production and manufacturing processes or even the daily use of products. These wastes might have the same composition of the products or the raw materials used in the production or even have a new composition that make them suitable to be used in another production process. Because of that, some wastes are even called industrial by-products. The increased industrial activities to respond to the demands of growing human population made the manufacturers think seriously of using these by-products through their production processes. In this field, the production of cement and concrete is considered very suitable to use by-products, because of the huge volumes produced and the nature of the production process. The fact that concrete is the most widely used construction material in the world and the issues created because of that, like pollution and consumption of natural resources, has made producing sustainable concrete a main concern for the manufacturers [Cheremisinoff, 2001 and 2003; Montana Department of Environmental Quality, 2006].

2.2 Importance of sustainability in cement and concrete production

During the production process of cement many materials are used either as raw materials or as fuel, but the use of these materials should not confront the ability of future uses of them. For example, limestone is the most common used raw material in cement production, and if this material runs out there will be no more cement, and all the works related to the concrete industry will come to an end. Therefore, a sustainable cement and concrete production should be carried out, which means that the total environmental impact during the products life cycle should be minimal. The sustainability of cement and concrete production implies low energy requirement, little waste production, the use of most abundant resources, producing durable structures and the ability of recycling. In order to meet part of the sustainability requirement of cement production, recently there is a growing emphasis on the use of waste materials in cement, the thing that also helps protecting the environment from waste pollution and saves energies and natural resources. Furthermore, when some wastes are used there is an ability to enhance and improve the cement and concrete properties in ways that cannot be reached by ordinary productions [Parrott, 2002; Naik, 2005; Siddique, 2008].

Grinding and heating processes in the cement production and the need for using filler materials in the concrete production make the use of wastes in these two products highly possible. The grinding process provides the necessary steps to reduce the particle size of the wastes, and the high temperature inside the kiln provides the appropriate ambient for changing the microstructure of the waste and acts also as a recycling process. As for the concrete, the use of cement as binding material with the aggregate as fillers makes it possible to replace the cement by wastes that have pozzolanic properties or simply to replace the aggregates by wastes that does not have any binding properties [EC BAT Cement, 2007; Sirchis, 2005].

It is clear when wastes are utilized in cement and concrete production, most of the benefits are in the environmental and economical sides. However, it is known that when some wastes - such as fly ash, silica fume and ground granulated blast furnace slag (GGBFS) – are utilized in cement and concrete production, some properties of concrete are improved. Despite that, it is not possible to use every waste in cement and concrete production, because there are some suitability requirements that need to be satisfied. For example, to use a waste as a fuel in cement production, the waste must have a sufficient calorific value, low heavy metal, chlorine and ash content and at the same time must be homogeneous and suitable for the burner. As for using wastes as raw materials for cement production, the most important point is the chemical suitability of the wastes so the constituent required for the production is always provided. On the concrete, the effects of using wastes can be measured from its influence on the concrete's workability, strength and durability properties. While some wastes have no effect on the concrete properties, others like fly ash, GGBFS or silica fume contribute in a very good way in that part. Besides that, the influence of the waste on the bleeding, consistency, permeability, air content, setting time and the resistance to the chemical attacks should be taken into consideration before using a waste in concrete [Mehta and Monteiro, 2006; Siddique, 2008].

2.3 Examples of wastes being used in cement and concrete

2.3.1 In clinker production

The production of clinker includes the preparation of the raw material mix and heating process in the rotary kiln. Due to the availability of crushers and mills in the cement factories, preparing the waste to be part of the raw mix is not a hard thing to do, but the effect of the waste on the abrasion of the machines and the amount of the energy needed to the preparation job needs to be considered. In the heating process, the high temperature in the rotary kiln normally guarantees the chemical decomposition of the waste, but the main concerns are the efficiency of the processing time, the negative effects of the waste on the kiln refractors, the generation of unwanted gases and the effects of the waste on the clinker properties [Labahn, 1983; Taylor, 1990].

With the increasing demand on ceramic tiles, the worldwide production has passed 7500 million m^2 in 2006 [Turkish Ceramic Federation Reports, 2006], and with approximately 12000 tons of ceramic waste generated for every 1 million m^2 tiles. The reuse of this waste in ceramic production is technically not viable, and usually the waste is deposited in dumping grounds. A study done by Peurtas et al. 2008, suggested, as an alternative, the use of this waste as a cement raw material that can be fed into the kiln. Raw mixes that contain fired red or white ceramic wall tile wastes or combination of the two wastes were prepared. The results of that study show that using this kind of wastes is feasible, and when the waste is ground to lower than 90µm the mixes showed better burnability and higher reactivity than the conventional raw mix [Puertas et al., 2008].

In the side of using wastes as fuels, the advantage of substitution fuel by waste tires is that tires have rapid combustion ability, high calorific value, around 31 MJ/kg, and also low moisture level. These reasons make the tire derived fuel (TDF) a very good supplemental fuel for the kiln burning process. Though, the ratio of the TDF should not exceed 30% of the fuel, as stated by a study of Pipilikaki et al., because of the large quantities of zinc presented in the clinker. To use tires as a fuel there are two methods, using the whole tire or processed tires. In the first method there are no additional expenses and the feeding system is very simple while the main advantage of the second method is that the calorific value is higher since there is less wire, bead and belt. In the same study of Pipilikaki et al., it was shown that when 6% of the fuel was replaced by TDF and the differences between the generated cement and the ordinary cement were found only in the setting time and the water demand [Pipilikaki et al., 2005].

Another study, performed by Trezza and Scian, evaluated the effect of the addition of small amounts of ashes from pyrolysis of used oil from cars in the clinkering process. The waste was used in various amounts up to 30%, and the effects of this addition on the properties of the obtained clinker were investigated and compared with ordinary Portland cement clinker (OPCC). The results showed different properties of the new clinker to the OPCC. The new product was more grindable and had higher initial reactivity during hydration and slightly higher compressive strength [Trezza and Scian, 2000].

2.3.2 In blended cement production

In this stage, the fineness and the moisture ratio of the waste material and its effect on the properties of the cement are the most important issues to consider. Here the wastes can be either ground with the clinker or mixed later with ground clinker. One of the most commonly used wastes in cement production is the granulated blast furnace slag (GBFS) which is actually considered as a by-product of iron. With mostly content of silicates and alumina from the iron ore, GBFS is counted as a good cementitious material when it is ground to a powder form. Ground GBFS usage is so common that in the Europe Norm EN 197-1 the third type of cement, CEM III, is called Blastfurnace Slag Cement. The main advantages that GBFS provides for concrete are low heat evolution and lower permeability, higher strength at later ages, lower chloride ion penetration, higher resistance to sulfate attack and alkali silica reaction. In EN 197-1, the cement replacement ratio by GBFS can go up to 95%. However, Khatib and Hibbert indicated that increase in the strength was only observed for replacement ratios up to 60% [Mehta and Monteiro, 2006; Osborne, 1999; Erdoğan, 2003; EN 197-1, 2000; Khatib and Hibbert, 2005].

Fly ash is also one of the widespread used materials as a cement replacement. It is a fine graded material which is generated from the combustion of the ground coal in power plants. Fly ash mostly contains silica, alumina and oxides of calcium and iron. Generally, fly ash can be divided into two categories:

- Class F: The fly ash generated from burning anthracite or bituminous coal is comprised in this category. This fly ash shows some pozzolanic properties.
- Class C: This class contains only fly ash produced from lignite or sub-bituminous coal. In addition to the pozzolanic properties, this fly ash has some cementitious properties as well.

In general, when cement is replaced with fly ash the water demand of the concrete and the bleeding ratio are reduced and the workability is improved. As for the strength, the type of fly ash and its fineness and dosage play an important part in the strength development of concrete. Like the GBFS, mixtures include fly ash generally shows higher strength at later ages [Wesche, 2005; ASTM C 618 REV A, 2008; Erdoğan, 2003; Siddique, 2008].

Another commonly used material in blended cement is silica fume, which is a pozzolanic material with high fineness, composed mostly of amorphous silica produced by electric arc furnaces as a by-product of the production of elemental silicon or ferrosilicon alloys. Due to its very high fineness, using silica fume in concrete improves its fresh properties by increasing the cohesion and reducing the bleeding, and it also enhances the mechanical properties and the durability of hardened concrete. However, due to its extremely fine nature, it cannot be used in high quantities [Holland, 2005; ASTM C 1240, 2005].

2.3.3 In concrete production

This stage contains the use of the waste in the concrete as a cement or an aggregate replacement. Here, the properties of the waste and its effect on the concrete's workability and durability and the need of a pretreatment of the waste play a big role in the usability of the waste. The most common use of waste in concrete is to replace cement with pozzolanic or self cementitious materials such as fly ash, silica fume and GGBFS. These replacements can easily be done in the concrete plants and are really beneficial from technical and economical sides.

In another trial to evaluate using wastes in concrete, Batayneh et al. have performed a study on the wastes like demolished concrete, glass and plastic. They suggested reusing the previous materials as a substitute for the aggregate in the concrete. Mixtures where the ground glass and plastics replaced 20% of the fine aggregate, and the crushed concrete parts replaced 20% of the coarse aggregate were prepared. An ordinary portland cement was used, and a number of tests were carried out to evaluate the effects of these replacements. The study stated that the irregular shape of the crushed concrete decreased the workability, while the replacement of ground glass and plastics did not show a significant effect on the workability. However the high alkali content of the crushed glass might have a negative influence on the long term durability. As for the strength using this type of wastes exhibited a decrease in the compressive strength, which limited its usage to certain purposes such non-structural applications [EC BAT Cement, 2007; Mehta and Monteiro, 2006; Batayneh et al., 2007].

The use of shredded tires in concrete was also investigated by many researchers. Ganjian et al. performed a study where scrap tires were used in concrete as cement and aggregate replacement. The results of that study showed that using scrap tires reduced the compressive strength of the concrete but in a lower ratio when it is used as aggregate replacement than when it is used as cement replacement. In a similar study, Atahan and Sevim [2008] used shredded tires as aggregate replacement in producing concrete barriers. That study concluded that concrete with addition of shredded tires with ratios of 20% to 40% results a reduction in vehicle peak deceleration forces and thus less impact strictness without significant reduction in the compressive strength [Ganjian et al., 2009].

2.4 Industrial wastes used in this study

Two types of wastes generated from local industries were evaluated in this study. These wastes already form disposing problems for the factories, and one of the suggested solutions for those problems is to evaluate their usability in concrete. In the following sections, the origin of these wastes and some of their properties and potential uses are presented.

2.4.1 Soda waste

Soda ash or sodium carbonate, Na_2CO_3, is a white, anhydrous, powdered or granular material that is considered as the fundamental raw material for the glass, detergent and other chemical industries. Soda ash either occurs naturally as a crystalline heptahydrate, or can be artificially produced. The waste produced during artificial production of Na_2CO_3 is called soda waste, or distiller waste. Briefly, the sources of this waste are the limestone and the salt used in the soda ash producing process [ESAPA, 2004].

The most common method of producing soda ash is the Solvay process where soda ash results from salt brine (source of sodium chloride, NaCl) and limestone (source of calcium carbonate, $CaCO_3$). In the Solvay process, the soda waste is the combination between the output wastes generated from the brine purification and ammonia recovery steps. The amount of impurities presented in this waste disqualifies it from being reused in the process again, and the quantity of the waste is directly related to the purity of the raw materials [Kasikowski et al., 2004].

Like any other waste nowadays, soda waste creates a real problem to the soda plants due to the environmental safety demands. Toward reducing the environmental negative impact of this waste, some studies have been done to use it in other applications, therefore limiting the bad influence of the soda plant on the environment. Among these studies, the utilization of soda waste in the production of gypsum came in front [Kasikowski et al., 2004]. The outcomes of that research indicated the possibility of using the soda waste to generate co-products (gypsum and semi-brine) in one process. Another study done by Şener, indicated that another possible way is to use the soda waste as an adsorbent for the removal of anionic dyes [Şener, 2008]. As for the cement industry, Kuznetsova et al. [2005], suggested using the soda waste in producing non-shrinking oil-well cement. In order to obtain sulfoferrite clinker, compositions of raw mixes that contain limestone, clay, cinders, gypsum, and soda waste were prepared. A control clinker, clinkers of low- and high-basic sulfoferrite and a clinker of intermediate composition were produced. Compressive strength and expansion tests were performed on the cements derived from the previous clinkers. The test results showed that obtaining sulfoferrite cement by using soda waste is possible, and the optimal composition was the high-basic sulfoferrite cement.

2.4.2 Beer waste

The beer waste studied in this thesis is the solid waste that comes from the filtration step of the beer production process, and contains the yeast separated from the beer along with the filtration material. There are many types of filters that are being used in this step like sheets, candles and fine powders like kieselguhr or perlite. The beer waste is a sludge material that may have a water content of about 60-65%, and it also includes an amount of organic materials. This waste forms a problem for the beer factories because it does not have yet a direct use in other fields [Priest and Stewart, 2006; Bamforth, 2003].

The filter type used in the beverage process, which the beer waste examined in this study came from, is kieselguhr. The name kieselguhr refers to the calcined grades of diatomaceous earth. The diatomaceous earth is naturally occurring mineral derived fossilized remains of marine diatoms, and it is considered as a natural pozzolanic material, which makes it suitable to be used in cementitious systems. This material is most commonly used for filtering purposes due to its highly porous nature. Since kieselguhr is a siliceous material, the solid part of the beer waste contains also a high amount of silica [Goldammer, 2000].

To dispose of beer waste, Blümelhuber [2007], suggested four methods: regeneration, dumping in a landfill, disposal over agricultural land and recycling into building material industry. The aim of regeneration method is to reuse the beer waste in the brewing process again, and to do so the waste must be processed chemically or thermally. Whereas methods like dumping or disposing over agricultural land needs no additional process and considers cheaper and easier but still subjected to some environmental regulations that may limit their use. As for using the waste in the building materials, the high level of SiO_2 and the fineness of the beer waste make it probable to be used in that field of industry. Blümelhuber indicated the possibility of that use in the production of calcareous sandstone, asphalt concrete and bricks. He also referred that properties of the generated products had been improved by using the beer waste. In the production of calcium silicate bricks, Russ et al. indicated that by using a ratio of about 1:2 of Beer waste to lime, the dehydrated lime or sand were reduced while the raw density and compressive strength standards were maintained. The particle distribution of in the mixtures was improved due to the porous structure of the beer waste [Russ et al., 2006].

2.4.3 Utilization of soda and beer wastes in cement and concrete

The two wastes are composed of fine materials which means that if they were to be used in cement production there is no need for grinding before adding them to the raw mix. But since they are in a sludge form, there will be an amount of wasted energy to dry them. On the other hand if they were to be used as raw materials for the clinker, in the soda waste the chloral content would be a concern hence the chlorinated compounds might not be totally destroyed in the kiln. While for the beer waste, organic contents will be destroyed. The use of these wastes in blended cements requires drying process first, and since they have a high water content, it will be costly. Therefore, in this study only the usability of these wastes in concrete was evaluated. Both wastes were hypothesized to be used in the production of self consolidating concrete (SCC) as a viscosity modifying agent, because of their fineness which is suitable for the higher amount of fine materials needed for SCC. Therefore, in the next section brief background and literature review of SCC will be presented.

2.5 Self Consolidating Concrete (SCC)

One of the most recent advances in concrete technology is SCC, which was first developed in Japan in the 1980s to enhance the durability of concrete. SCC was evolved through the years in different countries, and become a widespread type of concrete nowadays. According to ACI 237-R07, SCC is highly flowable, nonsegregating concrete that can be cast into place, fill the formwork, and condensed around the reinforcement without any mechanical consolidation. Generally, SCC is a type of concrete made with typical concrete materials along with viscosity-modifying admixtures. The higher compressive strength comparing to the conventional concrete, due to the lower water/cement ratio used, along with the properties mentioned above are the promoting reasons behind the use of SCC. The smooth surface, lesser labor and machines, improved work environment and safety, lower cost and faster construction rate are just samples of these reasons [ACI 237, 2007; Mehta and Monteiro, 2006].

2.5.1 Materials used in SCC

Basically, the materials used in SCC are the same of the conventional concrete with a change in the proportioning of those materials. As shown in Figure 2.1, one of the major differences between SCC and normal concrete is the amount of fine materials. The self consolidating characteristic of concrete can be reached by enhancing the properties of the mortar part of the concrete. Hence, increasing the amount of fine materials can produce the necessary mortar volume for SCC. The main binding material is cement that meets the standard specifications like ASTM C 150, C 595, or C 1157. Fine materials can be used also as a cement replacement like fly ash or silica fume, but attention is needed on the effect of these materials on the properties of the SCC, especially the workability. As for the aggregate, usually the nominal maximum size of the coarse aggregate is between 12 mm and 19 mm to acquire a good passing ability. The fine aggregate should be well graded, and usually its ratio is kept higher than the coarse aggregate. The most important materials, which make the difference of the SCC, are the chemical admixtures, such the Water Reducing Agents and Viscosity Modifying Agents. The ratios of the chemical admixtures are highly important because that even small variations in their dosage leads to significant differences in the SCC properties [Kosmatka et al., 2003; Mehta and Monteiro, 2006; Koehler and Fowler, 2007; ACI 237, 2007].

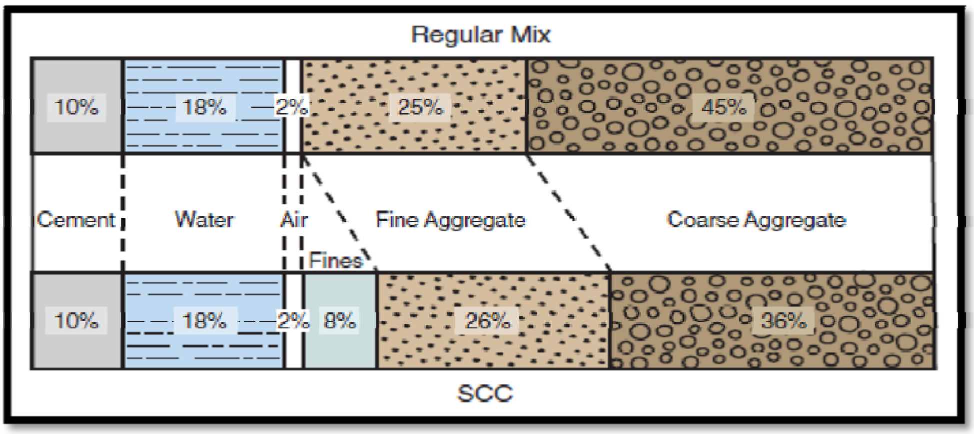


Figure 2.1 Examples of materials used in regular concrete and self-compacting concrete by absolute volume [Kosmatka et al., 2003]

2.5.2 Fresh and hardened properties of SCC

The most difference of SCC from conventional concrete is on the workability properties. While normal concrete needs a sort of mechanical method to fill the formwork, SCC has a higher filling and passing ability that allows it to fill all the spaces in the formwork passing all the obstacles on its way. Meanwhile, bleeding and segregation are considered as the main concerns of the SCC, which can be solved by the use of additives such Viscosity Modifying Agents. As for the hardened properties, SCC exhibits higher compressive and flexural strengths because of the lower water/cement ratio and the use of additives. The point that should be given attention is higher possibility for the SCC to be exposed to shrinkage, because of the high content of cement paste in the SCC [Koehler and Fowler, 2007; Lange, 2007].

2.5.3 Determining the fresh properties of SCC

There is no specific test method to measure the properties of the SCC. Common tests that are used in assessing the workability properties of SCC are relative tests to compare different mixtures of SCC. There are some limits and criteria defined for these tests to identify whether the concrete is considered a typical SCC or not. Some of the most common tests of the SCC are listed in Table 2.1. [EFNARC, 2005; Kumar, 2006; ACI 237, 2007].

Table 2.1 Tests of SCC

Test name	Test type	Measured property	Criteria
Slump flow	Filling ability	The spread diameter of a sample placed in standard slum cone.	55 cm < d <85 cm
J-ring	Passing ability	The spread diameter of a sample placed in standard slump cone through a ring attached to vertical steel bars	($d_{slump\ flow}$ - $d_{J\text{-}ring}$) < 1cm
T_{50}	Filling ability	The rate of flow of a sample placed in standard slum cone.	2 sec < T_{50} < 5 sec
V-Funnel	Filling ability	The rate of flow through a V shaped funnel	6 sec < T_V < 12 sec
L-Box	Filling and passing ability	The rate and the distance of flow through an L shaped box. The height of concrete at the start and the end of the box H1, H2	no limits for the time 0.8 < H2/H1 < 1.0
GTM segregation test	Resistance to segregation	The ratio of segregation	< 15%

2.5.4 Use of industrial by-products in SCC

As the amount of fine material in SCC production is high, as presented in Figure 2.1, the use of industrial by-products or wastes in SCC is quite common. For example, using fly ash (FA) in SCC is quite appropriate due to its fineness, pozzolanic activity and availability. In a study performed by Şahmaran, the properties of SCC with high volume of FA were investigated. The study showed that using both types of FA (low lime and high lime FA) with cement replacement ratios up to 70% in SCC is possible and can improve the workability and transport properties of SCC. A similar study accomplished by Khatib conducted that using FA as cement replacement in SCC with ratios up to 60% can produce concrete with compressive strength as high as 40 MPa [Şahmaran, 2006; Khatib, 2008].

Like fly ash, granulated blast furnace slag has also been used in SCC. Boukendakdji et al. carried out a study where the cement replaced with slag by ratios up to 25%. In that study an improvement of workability was observed with an optimum slag content of 15%, while the compressive strength decreased with the increase of slag. Another study done by Gesoğlu et al. showed that an incorporation of fly ash and slag with 10% ratio each can produce a SCC mixture with acceptable workability and high compressive strength of about 78 MPa [Boukendakdji et al., 2009; Gesoğlu et al., 2009].

The high fineness and amount of amorphous silica of silica fume make it very suitable to be used in SCC, but its high price and little available amount limit this usage. Although that using silica fume increases the compressive strength of SCC, it does not improve its fresh properties [Collepardi et al., 2004; Boukendakdji et al, 2009].

There are also other mineral materials that can be used with SCC. In a study performed by Christianto, limestone powder and brick powder were used. The results of that study showed that the use of limestone powder has increased the workability of SCC since it is very fine material, while it has no contribution in the compressive strength because it is inert filler. On the contrary, using brick powder has increased the compressive strength due to its pozzolanic activity, while it has not improved the fresh properties of SCC and even showed no self consolidating properties when its amount was increased [Christianto, 2004].

CHAPTER 3

EXPERIMENTAL PROCEDURE

3.1 General

This study was intended to evaluate the usability of soda and beer wastes in concrete. Due to the fine and adhesive nature of both materials, it was assumed that they may be utilized as viscosity modifying agents in SCC. Initial tests were performed by preparing mortars and observing the effects of using these wastes on the fresh and hardened properties of mortars. Later on, upon the results obtained from mortars tests that showed contradictions when beer waste was used, soda waste was chosen to prepare concrete mixtures and explore its effects on SCC.

The first tests were performed on mortars with a constant binder material ratio of 600 kg/m^3, where the cement was replaced by the soda and beer wastes. Two control mixtures, one of self consolidating mortar (SCM) with no cement replacement, and other of standard mortar mix, were made. To determine the properties of fresh mortar, tests of setting time, consistency, slump flow and V-Funnel were performed, and for the properties of the hardened mortar, compressive and flexural strength tests were carried out.

In the prepared SCC mixtures, the replacement type was of the fine aggregate, and for comparison a control mixture of SCC with no replacements was also prepared. The fresh properties of SCC were examined through slump flow time and diameter, V-Funnel, L-Box, air content, segregation ratio, bleeding ratio and setting time tests, while the hardened properties were observed through the compressive strength test. All the tests were performed at the Middle East Technical University, Materials of Construction Laboratory, except the chemical analysis and the particle size distribution of cement and wastes which were handled by Bolu Cement Company.

3.2 Materials

3.2.1 Cement

The cement type used in all mixtures prepared in this study was labeled as CEM I 42.5R according to TS EN 197-1, which was obtained from the local market and came in the form of 50 kg bags.

3.2.2 Soda waste

The soda waste used in this study was obtained from Şişecam Soda Sanayii, Mersin, Turkey. The waste came in the form of sludge with a water content of 69%, and a relatively low chloral content of 1.13%. Upon drying the sludge by heating in an oven at 110 ± 5 °C for a sufficient time to reach a constant mass, a material composed of fine particles was obtained.

3.2.3 Beer waste

The Beer waste used in this study was obtained from Efes Pilsen Beer Factory, Ankara, Turkey. This waste also came in sludge form with water content around 67%. By applying the same drying process used to dry the soda waste, a material composed of fine particles was also obtained.

3.2.4 Aggregates

In mortar tests, the aggregate used was CEN Standard Sand that conforms to EN 196-1. As for the concrete tests, crushed limestone aggregate type was used. Two types of coarse aggregates with different gradations, and one type of fine aggregate were used in preparing the concrete.

3.2.5 Chemical admixtures

In all of the mixtures, a polycarboxylic ether type superplasticizer, with a specific gravity of 1.1, a pH value of 7 and a solid content of 34% was used. The recommended dosage by the manufacturer for optimum results is 1.1% to 1.3% of the weight of binder material. The dosages used in mortar mixtures and concrete mixtures were 1.7% and 1.3% of the cement weight respectively. These higher amounts of superplasticizer (SP) were used to magnify the bleeding and segregation of the mixtures so that the viscosity modifying effects of the wastes can be better determined.

The air entraining admixture (AE) is normally used to produce freezing-thawing resisting concrete, and in this thesis it was only used in concrete mixtures for the same reason of using SP, magnifying the bleeding and segregation ratios. Ethanol and ammonium based air entraining agent with a specific gravity of 1.03, a pH value of 10, and a solid content of 14% was used. The recommended dosage by the manufacturer to get optimum results is 0.08% to 0.3% of the binder material's weight. The dosage used in the concrete mixtures was kept low, 0.06%, since the freezing-thawing resistance was not investigated.

3.3 Mixtures preparation

3.3.1 Mortar

Mortar mixtures were prepared using a standard mixer according to TS EN 196-1. The amount of binder material used in the self consolidating mortar (SCM) was kept constant at 600 kg/m^3, along with water and SP ratios, while the aggregate ratio was changed slightly to maintain the total volume of the mixtures equal to 1 m^3. The amounts of the replaced wastes were calculated based on their dry form. When the waste was added in sludge form its content of water was taken into consideration. The water amount was determined by trial until the desired fresh properties of the control mixture of SCM were reached. The mixture proportions are listed in Table 3.1. Soda waste was used in its sludge and dry forms while the beer waste was used in the dry form only. This is because of that the sludge soda waste is homogenous, and the content of water is constant in any part of it, while the sludge part in the beer waste consolidates in the bottom of the vessel through the time letting part of the water gather on the top, hence the water content of the beer waste sludge is not constant.

Table 3.1 Mix proportions of SCM

Mix ID			Powder ratio (kg/m^3)	Water/ Powder ratio	Components (kg/m^3)					
№	Code				Cement	SW*	BW*	Water	SP	Sand
1	SCM Control		600	0.45	600	-	-	270	10	1337
2	Dry	SW 5.0	600	0.45	570	30	-	270	10	1332
3		SW 10.0	600	0.45	540	60	-	270	10	1326
4		SW 15.0	600	0.45	510	90	-	270	10	1320
5	Dry	BW 5.0	600	0.45	570	-	30	270	10	1300
6		BW 10.0	600	0.45	540	-	60	270	10	1288
7		BW 15.0	600	0.45	510	-	90	270	10	1274
8	Sludge**	SW 2.5	600	0.45	585	15	-	270	10	1335
9		SW 5.0	600	0.45	570	30	-	270	10	1332
10		SW 7.5	600	0.45	555	45	-	270	10	1329
11		SW 10.0	600	0.45	540	60	-	270	10	1326
12	Standard Control		450	0.485	450	-	-	225	-	1350

* SW: Soda Waste, BW: Beer Waste.
**The amounts of the sludge soda waste are the total solid amounts.

Preparing and casting of the mortar specimens were done according to TS EN 196-1. First the water mixed with the SP was placed in the mixing bowl, and then the cement and the waste were added. The mixer was started immediately, and after 30 sec the sand was added to the mix. When the mixing process ended, the mortar was discharged and used in the slump flow test or V-Funnel test, or casted into a mold containing 3 spaces of 4 cm × 4 cm × 16 cm dimensions. In the casting process no consolidating method was applied except for the standard control mixture. After 24 hrs, the hardened specimens were removed from the molds and cured in water at a temperature of 20 ± 1 °C.

3.3.2 Concrete

Concrete mixtures were prepared by using an electrically powered revolving portable mixer with a capacity of 150 l. The amounts of cement, water/cement ratio, SP and AE were kept constant, while the amount of the aggregates was changed to maintain a total volume of 1 m^3. The replacement of soda waste was done with the fine aggregate. For the aggregates, ratios of 55% for fine aggregate, 20% for coarse1 and 25% for coarse2 of the total weight of the aggregate were used. The water content of aggregates and soda waste was taken into consideration in the mix design. The mixture proportions are listed in Table 3.2.

In the mixing procedure, first the fine and the coarse aggregates were placed in the mixer and mixed for about 2 min. But for mixtures with soda waste, first the coarse aggregates were placed then soda waste (in sludge form), and mixed together for about 4 min to perform a kind of grinding on the big sludge grains and let the sludge release part of its water content, and after that the fine aggregate was added and the whole were mixed for 2 min. Next the cement was added and the entirety was mixed for another 2 min before the mix of water-chemical admixtures was added. The mixing process starting from the water addition lasted 15 min. After that, part of the mixture was used to determine the fresh properties of the concrete through slump flow, V-Funnel, L-Box, air content, segregation, bleeding and setting time tests, and for the hardened properties of the concrete, a small part of the mixture was used for the drying shrinkage test, while the remaining part was cast into cylinders of 20 cm height × 10 cm diameter to be used later for the compressive strength tests. After 24 hours, the hardened specimens were removed from the molds and cured in water of a temperature of 20 ± 1 °C.

Table 3.2 SCC mixture proportions

Mix ID		Water Cement ratio	Concrete ingredients (kg/m^3)							
№	Code		Cement	Water	SP	AE	Soda waste*	Fine	Coarse1	Coarse2
1	SCC Control	0.42	500	210	6.5	0.3	0	913	333	416
2	SW 2	0.42	500	210	6.5	0.3	18	849	333	416
3	SW 4	0.42	500	210	6.5	0.3	37	876	333	416
4	SW 6	0.42	500	210	6.5	0.3	55	858	333	416
5	SW 10	0.42	500	210	6.5	0.3	91	821	333	416

*This amount is the total solid amount

3.4. Tests of chemical composition and physical properties of solid materials

3.4.1 Tests of fine materials

The chemical composition was obtained by X-Ray fluorescence (XRF). The ARL XRF 80-86 system was used for XRF analysis. The concept of XRF is the emission of characteristic X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays.

For the particle size distribution, a RODOS unit produced by Sympatec Company was used. The method used in this unit is dry dispersion for laser diffraction.

Finally, to find out the physical properties of the fine materials Le Chatelier flask apparatus was used to determine the specific gravity in accordance to ASTM C 188, and Blaine air-permeability apparatus to determine the fineness of the materials in accordance to ASTM C 204.

3.4.2 Tests of aggregates

The particle size distribution of aggregates was determined through sieve analysis in accordance to ASTM C 136, and the specific gravities were determined according to ASTM C 127 for coarse aggregate and ASTM C 128 for fine aggregate.

3.5 Tests on self consolidating mortar

3.5.1 Tests of the fresh properties

3.5.1.1 Slump flow diameter

For this test, a truncated cone as shown schematically in Figure 3.1.(a) was used. The cone was placed on a smooth plate, then the mortar was filled into it, and immediately the cone was lifted upward letting the mortar spread. After a sufficient time until the spreading stops, two perpendicular diameters were measured and their average d was taken as slump flow diameter. The relative slump flow diameter Γ_P can be calculated through equation **3.1**.

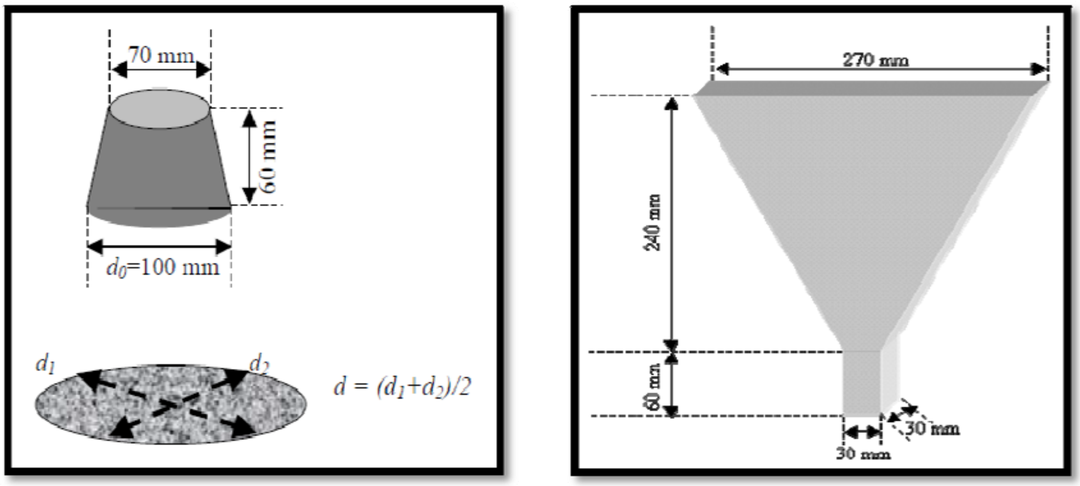
$$\Gamma_P = \left(\frac{d}{d_0}\right)^2 - 1 \qquad (3.1)$$

Where d_0 is the diameter of the control mix which is equal to 10 cm.

3.5.1.2 V-Funnel

A funnel of V shape as shown in Figure 3.1.(b) was used for this test. The funnel has a gate at the bottom which is kept closed during the filling process. After the funnel was filled with mortar, the gate was opened and time measuring was started. The elapsed time between opening the gate and the moment the light through the bottom gate was seen from the top of the funnel was measured and determined as V-Funnel flow time T_V. The relative V-Funnel time R_P can be calculated through equation **3.2**.

$$R_P = \frac{10}{T_V} \tag{3.2}$$



(a) Slump flow test (b) V-Funnel test

Figure 3.1 Schematic illustration of the flowability and workability tests applied to SCM

3.5.1.3 Consistency and setting time

These tests were performed in accordance with ASTM C 187 and ASTM C 191 using the Vicat apparatus. First the normal consistency of the mixture was determined. A 650 g of cement or binding material was mixed with a measured amount of water then the paste formed was put into Vicat ring according to

ASTM C 187. The penetration length of a free falling rod was measured, and the test was repeated with changes in the water amount till a penetration of 10 ± 1 mm was reached. The normal consistency was determined as the ratio of the last amount of water to the weight of cement or binder material. The last prepared paste was used to determine the initial and final setting time of the mixture according to ASTM C 191. Here, the penetration length of a free falling needle of 1 mm diameter is measured every 15 min until a penetration of 25 mm or less is measured. The time recorded between the start of the test and getting a penetration of 25 mm is the initial stetting time. The test is continued until a penetration of less than 1 mm is obtained, and the time required for that is recorded as the final setting time.

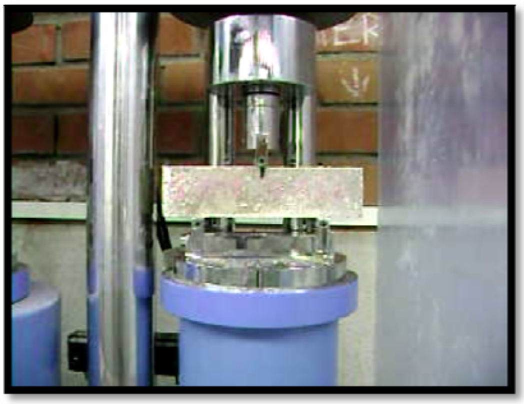
3.5.2 Tests of the hardened properties

3.5.2.1 Flexural strength

A three point bending test was used to determine the flexural strength of rectangular prism shaped mortar specimens with nominal dimensions of 160 mm × 40 mm × 40 mm, as seen in Figure 3.2.(a). The test was performed in accordance to TS EN 196-1 using a universal test machine. The maximum applied load P on the specimen was determined and the flexural strength R_f was calculated through equation **3.3**.

$$R_f = \frac{3PL}{2bd^2} \quad \textbf{(3.3)}$$

Where *L* is the span length (equal to 100 mm in this test), *b* the average width of the specimen and *d* is the average depth of the specimen. All the dimension are in mm, the load is in Newton and the flexural strength is in N/mm^2.



(a) Flexural strength test apparatus

(b) Compressive strength test apparatus

Figure 3.2 Illustrations of strength tests on mortar specimens

3.5.2.2 Compressive strength

Using the same testing machine as shown in Figure 3.2.(b), the compressive strength was determined in accordance to TS EN 196-1. The specimens used in this test were the ones taken from the flexural strength after the prism was broken into two parts, where the nominal dimensions of the square area subjected to compressive force are 40 mm × 40 mm. The maximum applied load P on the specimen was determined and the compressive strength R_c was calculated through equation **3.4**.

$$R_c = \frac{P}{A} \tag{3.4}$$

Where A is the area subjected to the compressive force, which is equal, in this test, to 1600 mm^2. The load is in Newton and the flexural strength is in N/mm^2.

3.6 Tests on self consolidating concrete

3.6.1 Tests of fresh properties

3.6.1.1 Slump flow

The aim of this test is to measure the free flowability of SCC in horizontal directions without obstacles. A similar cone of the one used in conventional slump test was used in this test, Figure 3.3. After the concrete was filled into the cone, the cone was immediately lifted up, and the time required for the spreading concrete to reach a diameter of 50 cm, T_{50} was measured. Then, and after waiting for a sufficient time for the spreading to stop, two perpendicular diameters were measured and their average was taken as slump diameter, d. For a concrete to be considered as SCC, T_{50} should be between 2 seconds and 5 seconds, while the diameter of slump flow should be in the range of 55 cm to 85 cm [EFNARC, 2005].

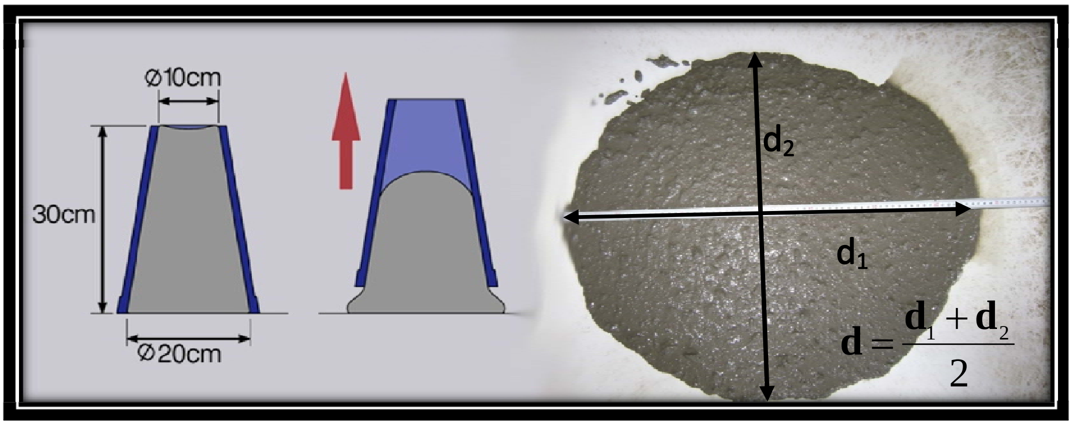
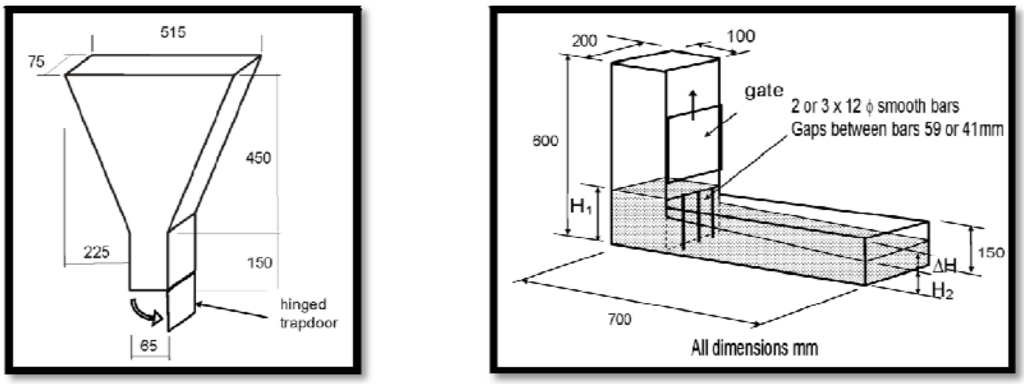


Figure 3.3 Slump Flow test

3.6.1.2 V-Funnel

This test is similar to the one performed in the mortar tests, but the dimensions of the funnel are bigger. The funnel used is shown in Figure 3.4.(a).



(a) V-Funnel (b) L-Box

Figure 3.4 Schematic illustration of SCC flowability and workability tests

3.6.1.3 L-Box

An L shaped box equipped with a gate next to the vertical part is the apparatus used for this test, Figure 3.4.(b). Right after the gate there are three reinforcing bars to form obstacles on the way of the concrete flow. The horizontal part is divided into three sections with 20 cm length each. The vertical part of the box was filled with SCC while the gate is closed. After the gate was opened, SCC has started to flow, and the time required for the concrete to reach the end of each section in the horizontal part was measured as T_{20}, T_{40} *and* T_{60}. There are no limits or recommended values for the times measured, but these values indicate the filling ability. At the end of the flow process, the average height of concrete in the vertical part H_1, and at the end of the horizontal part H_2, were measured. The ratio of H_2/H_1 indicates the slope of the concrete at rest and the passing ability, and should be between 0.8 and 1.0 according to EFNARC [EFNARC, 2005].

3.6.1.4 Vebe

This test is not used for SCC, but instead used for stiff concretes. The reason of using this test in this study was that the mixture which includes a 10% replacement of soda waste exhibited no slump, and for that, Vebe method was used to characterize its workability. Vebe test apparatus is showed in Figure 3.5. Like the normal slump test, the cone, placed inside a cylinder vessel over a vibrating table, was filled with concrete and consolidated with a metal rod. After the cone was removed the vibration process was started and the time elapsed from the start of the vibration till the concrete takes a complete cylindrical shape, was determined as Vebe time.

Figure 3.5 Illustration of Vebe test of concrete

3.6.1.5 Air content

The air content was measured from observation of the change in volume of concrete with a change in pressure. The test is done according to ASTM C 231, with a vertical air chamber. After the vessel was filled with concrete, the top part of the apparatus was firmly closed on the vessel. To expel the excess air found in the vessel, water was injected. After that, a sufficient amount of air was compressed into the vessel until the gauge hand was on the initial pressure line. Finally, the gauge pressure was released and the reading on the apparatus was recorded as the air content.

3.6.1.6 Segregation

To determine the segregation ratio, a test developed by the French contractor group Grands Travaux de Marseille (GTM), was performed. First a sample of 10 l of SCC was taken and hold for 15 min to allow any internal segregation to occur. Next, half of that sample was poured on a 5 mm sieve of 350 mm diameter. After 2 min, the amount of mortar passed the sieve was weighed. The percentage ratio of passed mortar weight to the weight of the original sample was recorded as the segregation ratio [Kumar, 2006].

3.6.1.7 Setting time

This test was performed in accordance to ASTM C 403. A sample of SCC was taken and poured on a 4.75 mm sieve. The mortar passed the sieve was filled into a cubic mold. Before performing the penetration test the bleeding water was removed from the top of the mortar. The penetration process was performed by using the loading device which has a load scale up to 667 N. The cross sectional area of the needle was 16 mm^2. Subsequent penetration tests were performed at half an hour intervals and the load reading of 25.4 mm penetration was obtained and converted to pressure amount by dividing it by the needle cross sectional area. The initial setting meets a pressure of 3.45 MPa, and the final setting meets a pressure of 27.6 MPa.

3.6.1.8 Bleeding

To measure the amount of bleeding, a process similar to the method used in ASTM C 232 was performed. A sample of SCC, with a mass of 15 ± 0.5 kg, was filled into a vessel placed on a vibrating table. The vibrating table was turned on for 30 sec every 5 min. The process lasted 1 hr. At the end of the process, the bleeding water was gathered with a syringe, and its volume was measured. The amount of bleeding in mm was expressed as the volume of bleeding water over the cross sectional area of the sample according to equation **3.5**

$$Bleeding\ (mm) = \frac{V_{water}}{A} \qquad (3.5)$$

Where V_{water} is the volume of bleeding water in mm^3, and A is the cross sectional area in mm^2.

3.6.2. Tests of hardened properties

3.6.2.1. Compressive strength

This test was performed on cylinder specimens with a diameter of 10 cm. The top and the bottom of the cylinder specimens were cut in a way that all the specimens had a final length of 15 cm. This operation was performed to have smooth cross sections of the specimens. The final diameter, length and weight of each specimen were measured. The compression test was performed by using a universal test machine, and unbounded neoprene pads for the capping. The calculation concept of the compressive strength of the concrete is determined by dividing the maximum load to the cross -sectional area, equation 3.6.

$$\sigma = \frac{P_{max}}{Area} \quad (3.6)$$

3.6.2.2 Drying shrinkage

Drying shrinkage is essentially a volume change that takes place over time due to moisture loss. To measure this change, mortar taken from SCC sample, which passed a 4.75 mm sieve, was cast into molds of dimensions of 2.5 cm × 2.5 cm × 27 cm. The specimens were removed from molds after 24 hour, and cured in water for one week. After that, the specimens were placed out of water in a room with 23 ± 4 °C and relative humidity of 50 ± 10%. The length of each specimen was measured every week to determine the length change. The shrinkage is obtained by dividing the length change to the initial length.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. General

In this section the data gathered from the experimental study conducted on the utilization of soda and beer wastes in cementitious systems are presented. The results are discussed and compared with the results of the previous studies published in the literature.

4.2. Chemical composition and physical properties of solid materials

4.2.1 Fine materials

The chemical compositions of cement, soda waste and beer waste are presented in Table 4.1 along with the physical properties of these materials. As seen in Table 4.1, due to its porous nature, the specific gravity of the beer waste is significantly lower when compared to the soda waste. When the fineness values are compared as obtained by the Blaine's air permeability apparatus, the beer waste seemed the coarsest and the soda waste the finest among the three powders. The particle size analysis revealed similar results to the Blaine's fineness results. The particle size distributions are presented in Figure 4.1. From this figure, it can be seen that the d_{50} of beer waste is about 20 µm, and for soda waste d_{50} is about 3 µm.

Table 4.1 Chemical compositions and physical properties of cement, dried soda and beer wastes

Chemical composition (%)	Cement	Soda waste	Beer waste
SiO_2	19.56	-	66.61
Al_2O_3	5.00	-	3.93
Fe_2O_3	3.68	2.06	4.33
CaO	64.55	49.22	2.31
MgO	1.57	3.20	-
SO_3	2.41	1.30	-
K_2O	0.66	-	0.34
Na_2O	0.77	0.52	1.88
Cl	-	1.13	-
Loss On Ignition	2.89	28.0	21.0
Physical properties			
Specific gravity	3.09	2.49	2.02
Blaine fineness (cm^2/g)	3370	5970	1820

4.2.2 Aggregates

The physical properties of sand used in self consolidating mortar (SCM) and aggregates used in self consolidating concrete (SCC) are presented in Table 4.2, while their particle size distributions, as determined by sieve analysis, are presented in Table 4.3. As seen from Table 4.2, all the aggregates have similar specific gravities. Coarse 2 aggregate had a maximum nominal size of 12.7 mm, whereas coarse 1 aggregate had a maximum nominal size of 16 mm.

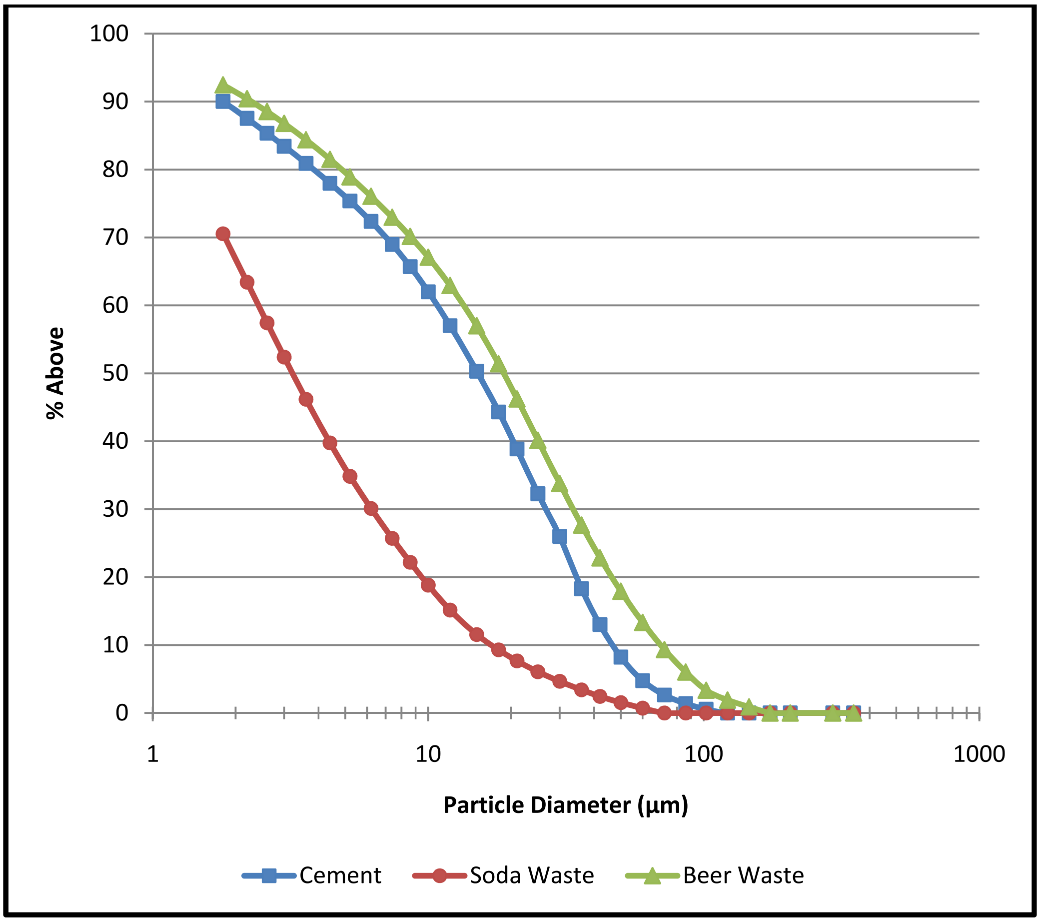


Figure 4.1 Particle size distribution of cement, soda and beer wastes

Table 4.2 Physical properties of aggregates

Aggregate type	Specific Gravity			Water Absorption (%)
	OD*	SSD*	Apparent	
CEN Standard Sand	2.56	2.52	2.54	0.68
Fine	2.64	2.66	2.70	0.75
Coarse1	2.67	2.68	2.70	0.42
Coarse2	2.66	2.67	2.70	0.52

*OD: Oven Dry, SSD: Saturated Surface Dry

Table 4.3 Particle size distribution of aggregates

Sieve size		Cumulative passing (%)			
Inch	mm	CEN Standard Sand	Fine	Coarse1	Coarse2
5/8	16	100.00	100.00	100.00	100.00
1/2	12.7	100.00	100.00	42.89	100.00
3/8	9.5	100.00	100.00	3.22	96.13
No. 4	4.76	99.73	99.80	1.76	47.69
No.8	2.38	88.73	73.80	0.00	6.17
No.16	1.19	66.02	46.12	0.00	2.91
No.30	0.59	38.07	29.48	0.00	2.36
No.50	0.297	15.10	19.72	0.00	2.11
No.100	0.149	5.10	14.64	0.00	0.00
Passing No.100		0.00	0.00	0.00	0.00

4.3 Effects of using soda and beer wastes as viscosity modifying agents in SCM

4.3.1 Fresh properties of SCM

4.3.1.1 Cone flow diameter and V-Funnel tests

There are no specific standards or limits for SCM tests, although the guidelines published by EFNARC in 2002 recommend target values of 24 to 26 cm for the slump flow diameter test and 7 to 11 sec for the V-Funnel time test. The tests were performed for comparison reasons, and they were repeated three times for soda waste and the average results were taken. For beer waste, these tests were performed only twice because of the big differences in the obtained results. The wastes were kept in the laboratory in sludge form, and were dried 2 days before each test. In Table 4.4, the cone flow diameter and the V-Funnel time of control mixtures and both cements, with dry soda waste and with dry beer waste, are presented along with the relative slump flow diameter Γ_P and the relative V-Funnel time R_P. Figures 4.2 and 4.3 show the relative slump flow diameter and V-Funnel time for soda waste addition, along with the minimum and maximum limits defined by EFNARC

Table 4.4 Fresh properties of SCM with dry soda and beer wastes

Mix ID			Cone flow		V-Funnel	
№	Code		Diameter (cm)	Relative Diameter Γ_P	time (sec)	Relative Speed R_P
1	SCM Control		27.0 ±1.0*	6.3	4.3 ±0.1	2.3
2	Dry	SW 5.0	27.2 ±0.7	6.3	4.0 ±0.1	2.3
3		SW 10.0	26.3 ±0.3	5.8	5.0 ±0.1	2.1
4		SW 15.0	24.2 ±0.2	4.8	6.2 ±0.2	1.6
5	Dry	BW 5.0	20; 15**	3.0; 1.3	4.0; 8.0	2.5; 1.3
6		BW 10.0	18; 12	2.2; 0.4	10.0; NF***	1.0; 0.0
7		BW 15.0	17; NF	1.9; 0.0	11.0; NF	0.9; 0.0
12	Standard Control		NF	0.0	NF	0.0
EFNARC			**24 - 26**	**4.8 - 5.8**	**7 - 11**	**1.4 - 0.9**

* ± numbers are the ± standard deviations from the average.
** Only two tests were performed for beer waste.
***NF: No Flow was observed.

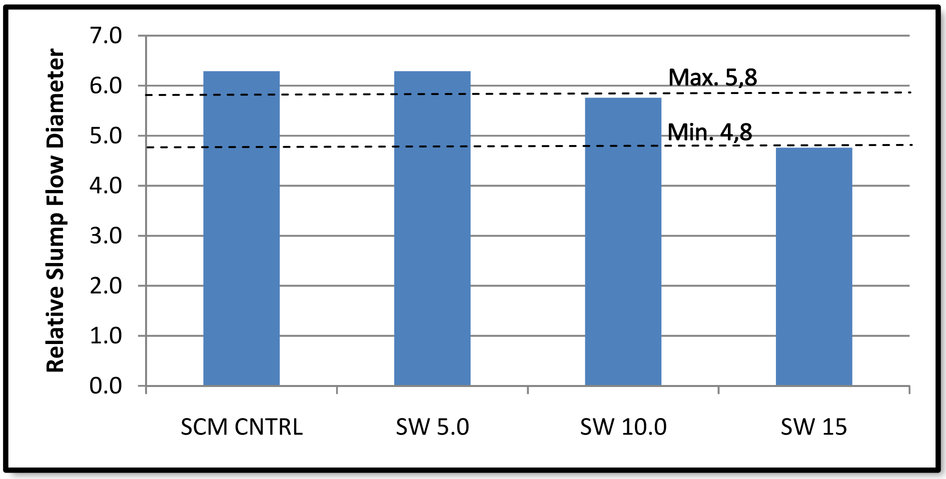


Figure 4.2 Relative slump flow diameter of SCM with dry soda waste

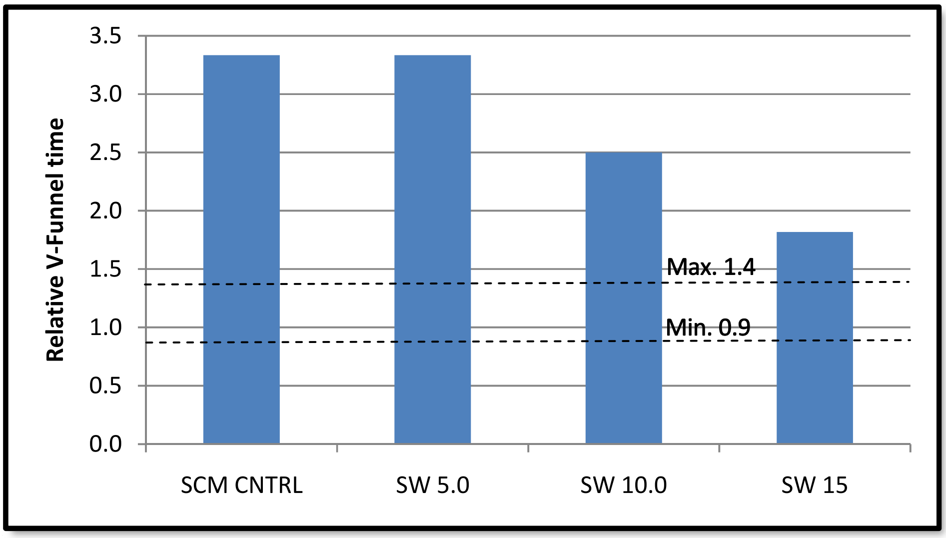


Figure 4.3 Relative V-Funnel time of SCM with dry soda waste

It's clear from the table that increasing the soda waste in the mixtures reduces the flowability which can be related to the fineness of soda waste. As the amount of fine materials increases, the flowability of the mixes is adversely affected, considering that the water content was kept constant. It should also be noted that the soda waste replaced the cement by its mass percentage, and since the specific gravity of soda waste is significantly lower; the volume of cement replaced by soda waste is significantly higher. Therefore, the volume of fine material is significantly increased. A similar behavior was reported by Holland [2005] when silica fume was used in concrete, and that was because of the extremely fine nature of silica fume.

The big differences in results when beer waste was used, is speculated to be a consequence of the organic materials content found in the beer waste sludge.

The presence of the yeast in this waste may let the fermentation process continue which may lead to a change in the chemical composition of the waste. As the beer waste was only dried at a temperature of 100 °C, it is believed that not all the organic materials were thought to be removed from the waste.

4.3.1.2 Consistency and setting time tests

Consistency test results, presented in Table 4.5, revealed that adding soda waste increases the water requirement of the mixture to reach a constant consistency, because of the high fineness of the soda waste. As for the setting time, using soda waste decreased the initial setting time and the setting period, because of its calcium chloride ($CaCl_2$) content (calcium chloride is a by-product of Solvay process), which accelerates the hydration and hardening of tricalcium silicate [Ramachandran, 1984]. These tests were not performed for beer waste because of differences in results obtained in the tests of the previous section.

Table 4.5 Consistency and setting time of SCM with dry soda waste

Mix ID №		Code	Water requirement (%)	Initial setting time (hour)	Final setting time (hour)	Setting period (hour)
1	SCM Control		21	4:30	7:30	3:00
2	Dry	SW 5.0	22	2:50	5:20	2:30
3	Dry	SW 10.0	23	2:35	4:50	2:15
4	Dry	SW 15.0	24	2:00	4:15	2:15
12	Standard Control		24	2:00	4:15	2:15

4.3.2 Hardened properties of SCM

The flexural and compressive strength of the mortars were determined at 2, 7 and 28 days for soda waste, and 7 and 28 days for beer waste. Flexural tests were performed on 6 specimens and the compressive tests on 12 specimens for each mix. Table 4.6 contains the flexural strength test results while Table 4.7 contains the compressive strength test results along with the density of the mixtures. Table 4.8 present the pozzolanic strength activity index of dry soda and beer wastes [ASTM C 618 REV A, 2008]. The effects of dry soda and beer wastes on the compressive strength are also presented in Figures 4.4 and 4.5.

Table 4.6 Flexural strength of SCM with dry soda and beer wastes

Mix ID			Flexural Strength (MPa)		
№	Code		2 days	7 days	28 days
1	SCM Control		8.5 [2]*	9.4 [7]	10.1 [4]
2	Dry	SW 5.0	5.2 [5]	6.1 [6]	6.2 [7]
3	Dry	SW 10.0	4.2 [4]	5.0 [8]	5.3 [5]
4	Dry	SW 15.0	3.4 [4]	4.3 [7]	5.1 [4]
5	Dry	BW 5.0	-	3.3 [2]	5.0 [7]
6	Dry	BW 10.0	-	3.3 [5]	5.1 [7]
7	Dry	BW 15.0	-	5.4 [6]	5.5 [11]
12	Standard Control		7.1 [4]	8.3 [5]	10.5 [6]

*The numbers in brackets are the coefficients of variation (%).

Table 4.7 Compressive strength of SCM with dry soda and beer wastes

Mix ID			Compressive Strength (MPa)			Density (kg/m^3)
№		Code	2 days	7 days	28 days	
1		SCM Control	38 [3]*	43 [15]	52 [5]	2178
2	Dry	SW 5.0	33 [4]	37 [9]	40 [7]	1948
3	Dry	SW 10.0	26 [3]	31 [6]	33 [5]	1907
4	Dry	SW 15.0	19 [4]	24 [5]	30 [6]	1894
5	Dry	BW 5.0	-	15 [7]	23 [10]	1903
6	Dry	BW 10.0	-	12 [14]	25 [9]	1851
7	Dry	BW 15.0	-	26 [13]	29 [17]	1788
12		Standard Control	24 [3]	33 [7]	49 [3]	2194

*The numbers in brackets are the coefficients of variation (%).

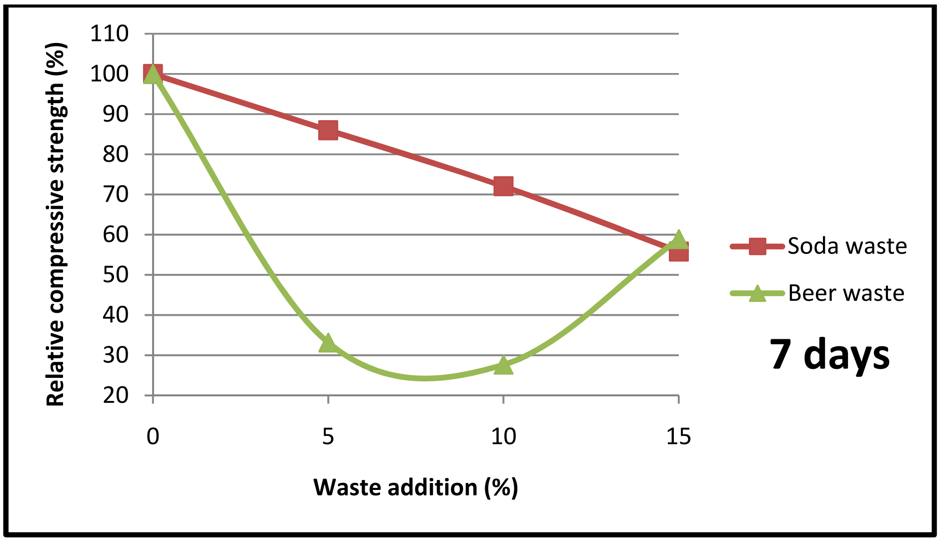


Figure 4.4 Change in 7 day compressive strength of SCM with the addition of dry soda and beer wastes

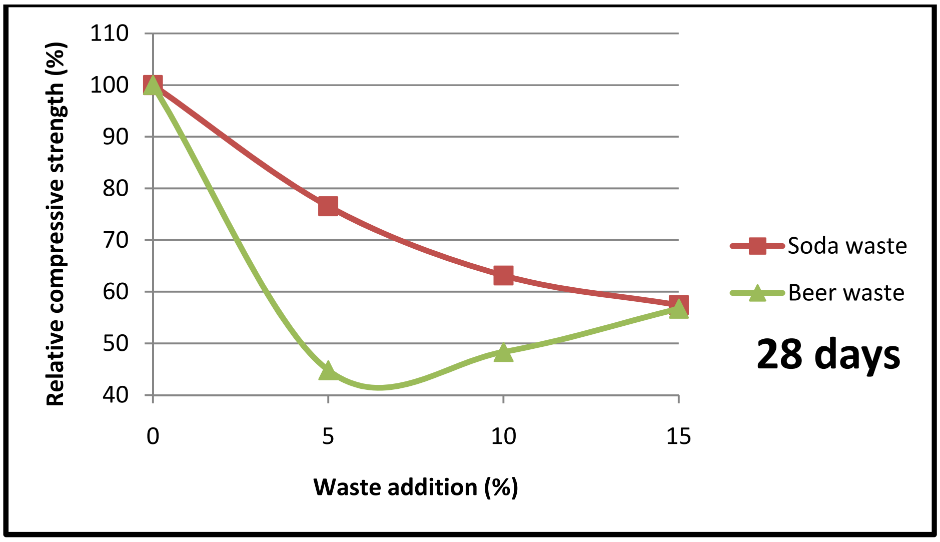


Figure 4.5 Change in 28 day compressive strength of SCM with the addition of dry soda and beer wastes

Table 4.8 Pozzolanic activity index of dried soda and beer wastes

Mix ID		Flow diameter (cm)	Water requirement ratio	Compressive Strength			
				7 days		28 days	
№	Code			Value (MPa)	Percent	Value (MPa)	Percent
12	Standard Control	21.9	100%	33	100%	49	100%
13	Dry soda waste	21.9	125% > 115%	10	30% < 75%	16	32% < 75%
14	Dry beer waste	21.9	128% > 115%	3	9% < 75%	4	8% < 75%
15	Beer waste original filter material	21.9	143%>115%	22	60%<75%	40	88%>75%

Note: The water requirement ratio should not exceed 115%, and the compressive strength should be more than 75% of the standard control mix for the material to be considered having pozzolanic activity.

As it is seen from these results, the use of soda waste had no contribution in the strength development, thus, the more soda waste used as cement replacement the less strength was obtained. The absence of soda waste role in the strength development of mortars can be also seen from the results of the pozzolanic strength activity index. This indicates that soda waste is an inert material; hence the decreasing in strength when the soda waste is used can be related to the decrease of cement amount in the mixtures.

The results of the compressive strength and the pozzolanic strength activity index tests of beer waste SCM show inconsistency because even though beer waste has no pozzolanic activity, the compressive strength of mixture with higher content of beer waste, 15%, was higher than the other two mixtures. However, the high coefficient of variation for 15% replacement of beer waste should be noted. Compared to the pozzolanic activity of the original filter material of beer waste, which is presented in Table 4.8, the inert activity of beer waste and the contradictions mentioned above can be related to the content of organic materials that came from the filtration process.

4.4 Effects of sludge soda waste addition on SCM and SCC

After the contradiction in test results when beer waste was used, it was decided to continue the experimental study on soda waste only, and examine its effect on SCC. Since it is more economical to use the soda waste in concrete without pretreatment (drying), first the ability of using sludge soda waste as cement replacement in SCM was evaluated. Then, upon the results obtained from SCM, the effects of using sludge waste as aggregate replacement in SCC were examined.

4.4.1 Effect of sludge soda waste addition on SCM

4.4.1.1 Fresh properties of SCM

4.4.1.1.1 Cone flow diameter and V-Funnel

The results of the flowability tests are presented in Table 4.9 and Figures 4.6 and 4.7. The behavior obtained when dry soda waste was used can also be seen here, increasing the soda waste in the mixtures reduces the flowability. From another side, using the waste in the sludge form reduces the flowability more than if it is used in the dry form. This is presumed to be because of the water found in the sludge was not totally released during the mix process, because of the shearing rate is not that high when mixing. It should also be noted that especially for higher replacement ratios, the flocculation of soda waste could not be prohibited. White deposits of soda waste could be seen in the hardened specimens, as shown in Figure 4.8.

Table 4.9 Fresh properties of SCM with sludge soda waste

Mix ID			Cone flow		V-Funnel	
№	Code		Diameter (cm)	Relative Diameter $Γ_P$	time (sec)	Relative Speed R_P
1	SCM Control		27.0 ±1.0	6.3	4.3 ±0.1	2.3
8	Sludge	SW 2.5	26.5 ±0.5	5.8	4.3 ±0.1	2.3
9		SW 5.0	25.3 ±0.3	5.3	4.8 ±0.1	2.1
10		SW 7.5	23.3 ±0.3	4.3	5.8 ±0.2	1.7
11		SW 10.0	16.0 ±0.5	1.6	15.4 ±1.0	0.6
12	Standard Control		10	0.0	No Flow	0.0
EFNARC			**24 - 26**	**4.8 - 5.8**	**7 - 11**	**1.4 - 0.9**

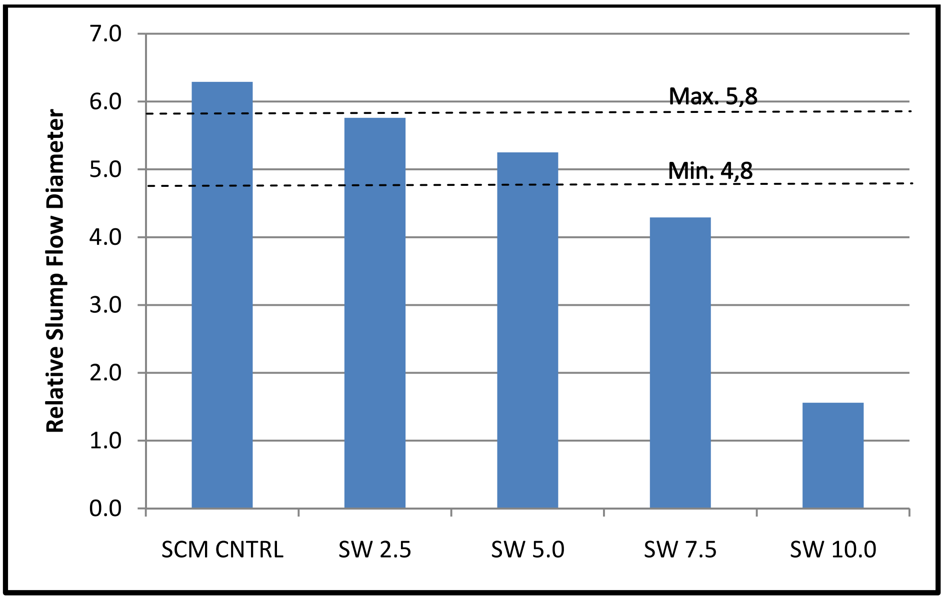


Figure 4.6 Relative slump flow diameter of SCM with sludge soda waste

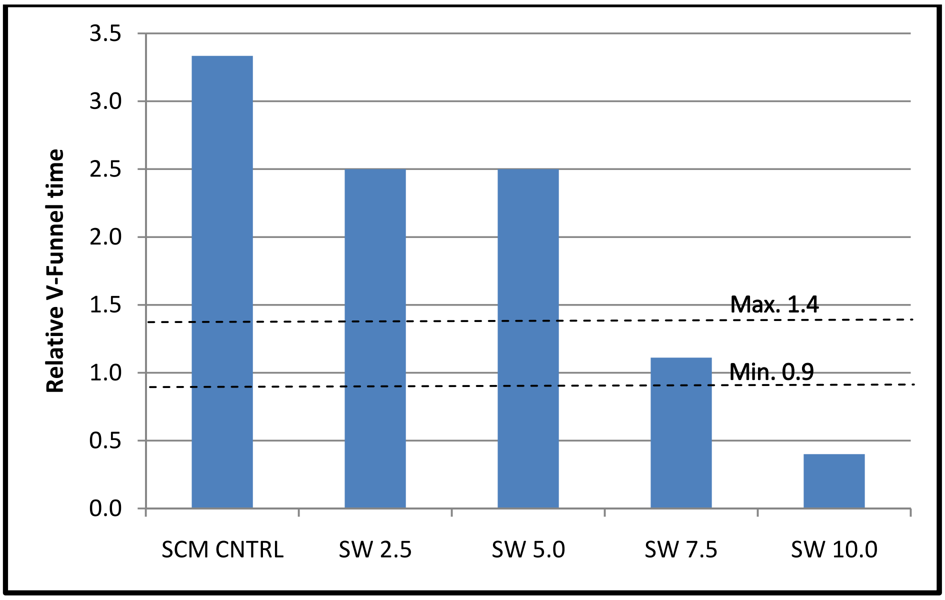


Figure 4.7 Relative V-Funnel time of SCM with sludge soda waste

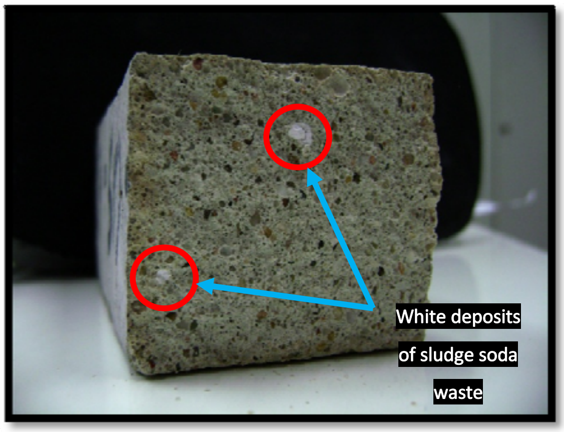


Figure 4.8 Cross section of SCM with 10% addition of sludge soda waste

4.4.1.1.2 Consistency and setting time

In Table 4.10, the results of consistency and setting time tests are presented. Consistency test results showed that adding soda waste increase the water requirement of the mixture to reach a constant consistency, because of the high fineness of the soda waste particles and the amount of water bound to the soda waste when it is used in the sludge form. As for the setting time, using soda waste decreased the initial setting time and the setting period, presumably because of its calcium chloride ($CaCl_2$) content as explained in section 4.3.1.2

Table 4.10 Consistency and setting time of SCM with sludge soda waste

Mix ID			Water requirement (%)	Initial setting time (hour)	Final setting time (hour)	Setting period (hour)
№	Code					
1	SCM Control		21	4:30	7:30	3:00
8	Sludge	SW 2.5	22	4:05	6:45	2:40
9	Sludge	SW 5.0	24	3:15	5:30	2:15
10	Sludge	SW 7.5	25	2:35	4:10	1:35
11	Sludge	SW 10.0	27	2:00	3:00	1:00
12	Standard Control		24	2:00	4:15	2:15

4.4.1.2 Hardened properties of SCM

Like the results obtained when dry soda waste was used, the results of flexural and compressive strength tests of sludge soda waste SCM showed that this waste takes no role in the strength development. Test results are presented in Tables 4.11 and 4.12. There is a slight increase in the early compressive strength of SCM when 2.5% of cement was replaced by the soda waste, as seen in Figure 4.9. This is probably because of the alkaline environment present in the soda waste which acts as a strength accelerator. The decrease in the compressive strength, when the amount of soda waste replacement increases, can be related to the reduction in the cement content.

Table 4.11 Flexural strength of SCM with sludge soda waste

Mix ID			Flexural Strength (MPa)		
№	Code		2 days	7 days	28 days
1	SCM Control		8.5 [2]*	9.4 [7]	10.1 [4]
8	Sludge	SW 2.5	8.2 [3]	9.3 [7]	9.5 [6]
9	Sludge	SW 5.0	6.6 [5]	7.7 [11]	9.4 [5]
10	Sludge	SW 7.5	7.1 [2]	7.6 [4]	8.6 [3]
11	Sludge	SW 10.0	6.7 [6]	7.0 [5]	8.1 [3]
12	Standard Control		7.1 [4]	8.3 [5]	10.5 [6]

*The numbers in brackets are the coefficients of variation (%).

Table 4.12 Compressive strength of SCM with sludge soda waste

Mix ID			Compressive Strength (MPa)			Density
№	Code		2 days	7 days	28 days	(kg/m^3)
1	SCM Control		38 [3]*	43 [15]	52 [5]	2178
8	Sludge	SW 2.5	40 [4]	45 [5]	52 [8]	2036
9	Sludge	SW 5.0	29 [4]	39 [13]	50 [9]	1954
10	Sludge	SW 7.5	26 [3]	33 [6]	36 [4]	1901
11	Sludge	SW 10.0	24 [3]	30 [5]	33 [10]	1880
12	Standard Control		24 [3]	33 [7]	49 [3]	2194

*The numbers in brackets are the coefficients of variation (%).

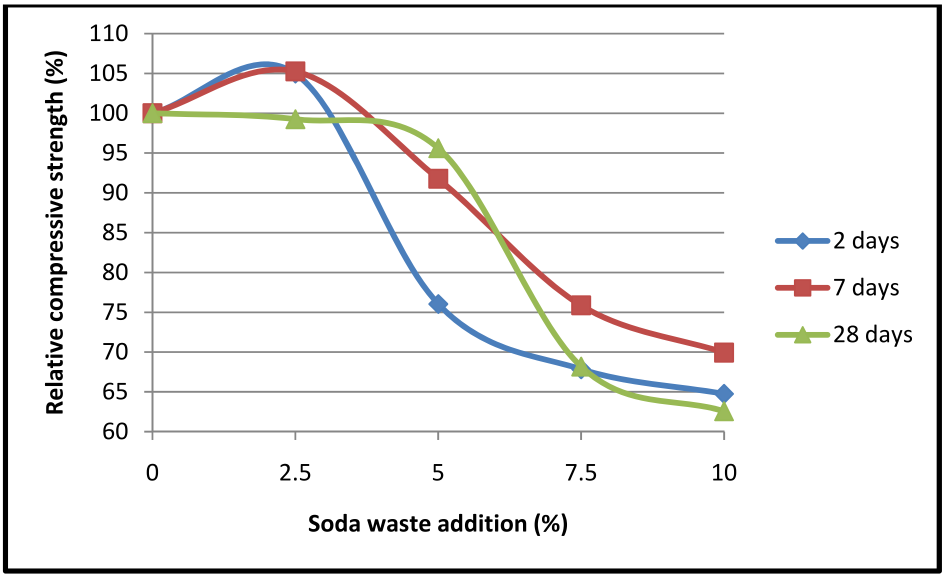


Figure 4.9 Change in the compressive strength of SCM with the addition of sludge soda waste

4.4.2 Effect of sludge soda waste addition on SCC

4.4.2.1 Fresh properties of SCC

As mentioned in Chapter 3, the aim of adding soda waste is to use it as a viscosity modifier. To examine the effect of this addition on SCC in a better and clear way, a control mix with high bleeding and segregation ratios was designed using high dosage of superplasticizer and a small addition of air-entraining agent along with a relatively high water/cement ratio. Increasing the soda waste ratio added to the mixture has enlarged the viscosity of the concrete as it can be seen from the results of the tests in the following sections.

4.4.2.1.1 Slump flow test

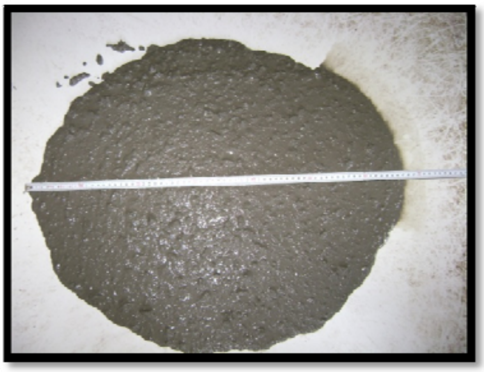
The slump flow time T_{50} and the slump diameter flow tests results are presented in Table 4.13. The results indicate that adding soda waste increased the adhesion in the concrete and reduced the flowability of SCC, and when the addition amount was above 4% of the fine aggregate the mixtures were no longer flowable as can be seen from both slump flow time and diameter data. It should be noted that mix 1, which does not contain any soda waste, had considerable amount of bleeding as it was originally planned. On the other hand mix 4 and 5, which had 6% and 10% of soda waste respectively, yielded what is called shear slump (where part of the slumped concrete collapses and the remaining part retains the cone shape), and zero slump concrete. Figure 4.10 shows some photos of the performed slump flow tests.

Table 4.13 Slump flow tests results of SCC with sludge soda waste

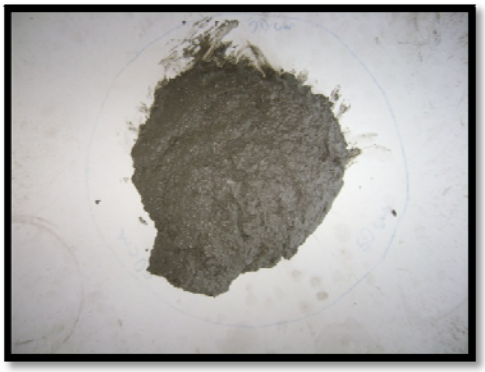
Mix ID		Slump flow		V-Funnel time (sec)
№	Code	T_{50} (sec)	Diameter (cm)	
1	SCC Control	2.0	76	28.0
2	SW 2	2.5	75	7.5
3	SW 4	3.5	69+58*	9.5
4	SW 6	NA	Shear failure	NA
5	SW 10	NA	NA	NA
Limits of EFNARC		2.0 - 5.0	55 - 85	6.0 - 12.0

*The shape of the spread core was not circular, and two diameters were reported.

(a) Mix 1, high bleeding ratio



(b) Mix 3, low bleeding ratio



(c) Mix 4, shear slump

(d) Mix 5, zero slump

Figure 4.10 Slump flow test results of SCC with sludge soda waste

4.4.2.1.2 V-Funnel test

In Table 4.13, the results of the V-Funnel test are also presented. The values of mix 2 and mix 3 are in the acceptable range of EFNARC. While the results of the mixtures contain soda waste meet logically the results of the slump flow test, the high value of mix 1 is related to the segregation that occurred during the test, which made the flow of the paste earlier from the gate resulting in the accumulation of larger particles blocking the gate. The reduction of the V-Funnel flow time for the mixtures containing 2% and 4% soda waste therefore shows the enhancement in the viscosity of the mix which reduces the segregation observed for the control mix.

4.4.2.1.3 L-Box test

This test was performed to evaluate the flowability and workability of SCC. The results of this test are given in Table 4.14. It can be seen from the results that mix 3 is the only mixture that specify the height difference required by EFNARC. Although the flow times (T_{20}, T_{40} and T_{60}) of the first three mixtures are very close to each other, the variation of the final heights results can be explained as a result of the segregation taken place behind the reinforcement bars at the gate where the bars keep the coarse aggregate from going through and a large amount of concrete remained in the first part.

Table 4.14 Results of L-Box test of SCC with sludge soda waste

Mix ID		T_{20}	T_{40}	T_{60}	H_2/H_1
№	Code				
1	SCC Control	2	4	9	0.64
2	SW 2	2	4	7	0.75
3	SW 4	3	5	8	0.80
4	SW 6	NA	NA	NA	NA
5	SW 10	NA	NA	NA	NA
EFNARC		-	-	-	0.80 - 1.00

4.4.2.1.4 Vebe test

This test was performed only on SW 10 mixture, because it exhibited zero slumps. The Vebe time obtained was 9 seconds, which indicates that the concrete has low workability according to ASTM C 1170, and shows that adding soda waste reduces workability.

4.4.2.1.5 Air content test

Using the type A air meter indicated in ASTM C 231, the air contents of SCC mixtures were measured. The results are presented in Table 4.15 along with the fresh unit weight of the mixtures. It is clear from the results that adding soda waste increases the air content of the mixture, since the air content value increases in conjunction with a decrease in the fresh unit weight. The odd results obtained for mix 5 is because the mechanical consolidating process with a metal rod used in placing the concrete in the measuring bowl, as this mix was very stiff as indicated previously in section 4.4.2.1.1.

Table 4.15 Results of air content test and the fresh unit weight of SCC with sludge soda waste

Mix ID		Air content %	Fresh unit weight (kg/m^3)
№	Code		
1	SCC Control	5.8	2208
2	SW 2	7.0	2188
3	SW 4	11.0	1943
4	SW 6	13.0	1940
5	SW 10*	3.8	2228

* Compaction was applied for this mixture

4.4.2.1.6 Segregation test

Results of this test get along with the results obtained in the previous tests performed in this study. Segregation ratio decreased along with the increase of soda waste ratio, which can be related to the cohesive nature of the soda waste. The test results are given in Table 4.16.

4.4.2.1.7 Setting time

The initial and final setting times for the first four mixtures were measured, and the results are presented in Table 4.16. It can be indicated from these results that the initial setting time and the setting period decreased proportionally with the increase of soda waste ratio. This can be related to the calcium chloride ($CaCl_2$) content of soda waste.

Table 4.16 Results of segregation, bleeding and setting time tests of SCC with sludge soda waste

Mix ID		Segregation ratio (%)	Bleeding (mm)	Setting time (hour)	
№	Code			Initial	Final
1	SCC Control	50	1.88	7.0	12.5
2	SW 2	37	0.19	4.0	8.5
3	SW 4	25	Not observed	3.5	6.5
4	SW 6	3	Not observed	3.0	5.0
5	SW 10	Not tested	Not observed	Not tested	Not tested

4.4.2.1.8 Bleeding

Bleeding was observed only in mix 1 and mix 2 with an apparent decrease in mix 2 when the soda waste was added. The decrease of bleeding ratio is due to the increase in water requirement by soda waste, because of its adhesive nature and fineness, and the use of soda waste in the sludge form when part of the water content is already adsorbed by the fine particles of the soda waste. The test results are shown in Table 4.16.

4.4.2.2 Hardened properties of SCC

4.4.2.2.1 Compressive strength

The compressive strength test was performed at 7 and 28 days on six cylindrical specimens using unbounded neoprene pads each time. Test results, presented in Table 4.17 and Figure 4.11. From the figure, it can be seen that when soda waste was added up to 4%, the decrease in 28 day compressive strength was little, around 10%, while it was around 40% when the replacement ratio was 6%. The strength decrease when soda waste was added as aggregate replacement can be related to increase in the amount of air voids along with the increase of soda waste amount. The high compressive strength value of the mix 5 is because the concrete was consolidated with a metal rod. But this value is also important as it shows that with the compaction of concrete relatively higher strength concrete would be observed while utilizing 91 kg/m^3 of solid amount of soda waste.

Table 4.17 Compressive strength test results of SCC with sludge soda waste

Mix ID		Compressive strength (MPa)	
№	Code	7 days	28 days
1	SCC Control	34.7 [5]	39.5 [9]
2	SW 2	32.8 [11]	36.0 [8]
3	SW 4	25.4 [10]	35.2 [9]
4	SW 6	20.1 [13]	23.0 [10]
5	SW 10*	33.1 [15]	42.9 [12]

* Compaction was applied for this mixture

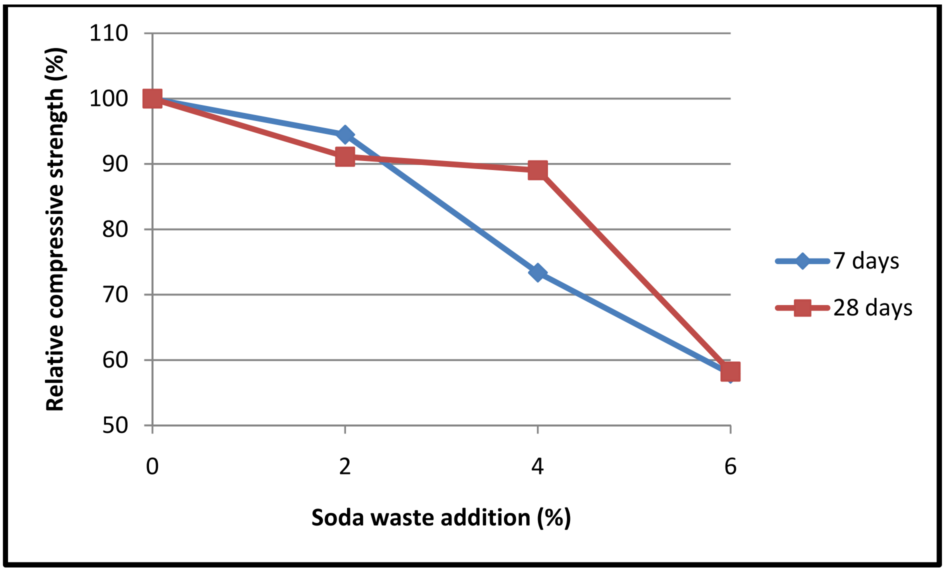


Figure 4.11 Change in the compressive strength of SCC with sludge soda waste addition

4.4.4.2.2 Shrinkage test

The length measurement of specimens from the first four mixtures was performed for six weeks and the results are given in Table 4.18 and Figure 4.12. From the results it can be said that all the mixtures had moderate shrinkage. And since that the difference of drying shrinkage between the control mixture and the mixtures that contain soda waste is not significant, it can be said that adding soda waste have no direct effect on the shrinkage properties of SCC.

Table 4.18 Drying shrinkage test results of SCC with sludge soda waste

Mix ID		Strain (× 10^{-6})					
№	Code	1^{st} week	2^{nd} week	3^{rd} week	4^{th} week	5^{th} week	6^{th} week
1	SCC Control	88	-283	-327	-298	-322	-415
2	SW 2	71	-340	-323	-384	-469	-548
3	SW 4	180	-288	-399	-376	-340	-475
4	SW 6	164	-372	-235	-253	-377	-527

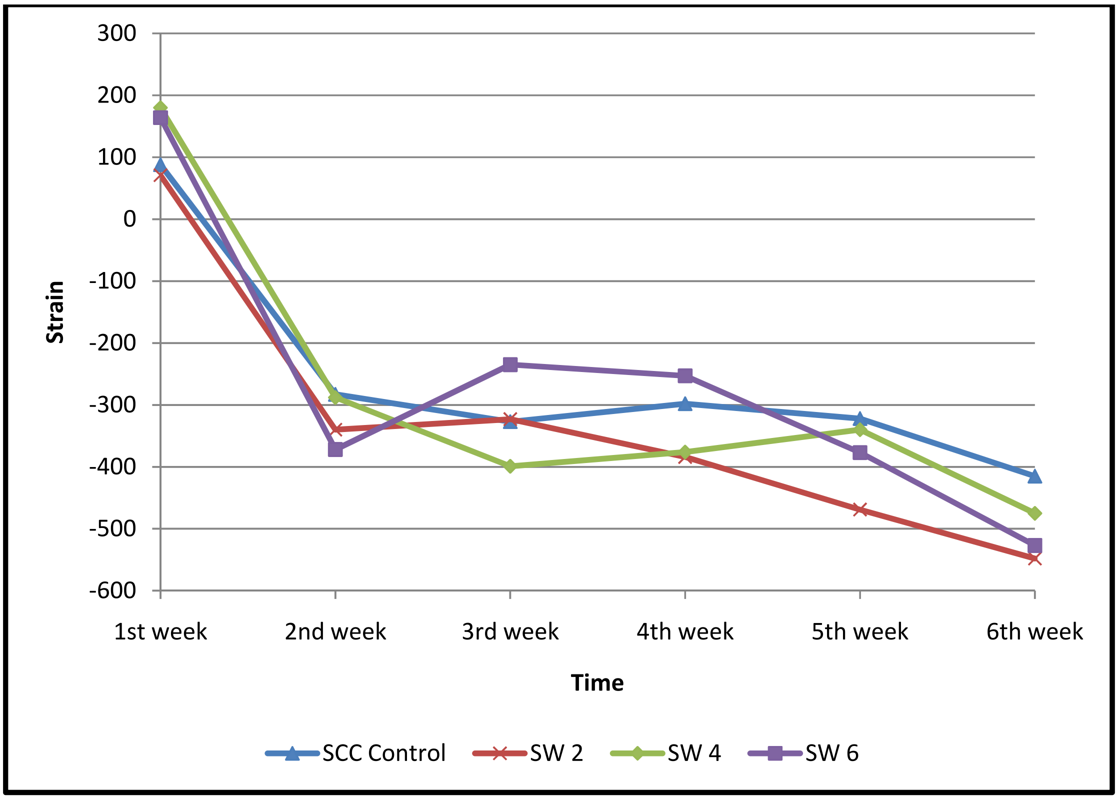


Figure 4.12 Strain values of SCC with sludge soda waste through the time

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 General

The usability of soda and beer wastes in cementitious systems was evaluated in this study, and the case of SCM and SCC was examined. First, mortar mixtures that contain cement replaced by various ratios of soda and beer wastes were prepared and the fresh and hardened properties of these mixtures were determined. Upon the results obtained from mortar tests, the examination continued on SCC with soda waste as aggregate replacement, and again, the fresh and hardened properties of the concrete were measured.

From the results obtained in this study, the following conclusions can be drawn:

- The use of soda and beer wastes as viscosity modifying agents is possible. The soda waste revealed logical behavior, while the beer waste exposed contradicting results due to its organic content.

- Both wastes have no contribution to the strength development of mortars, and the strength reduced when they are used as cement replacement.

- Since the soda waste takes no role in the compressive strength development, it could be used as an aggregate replacement instead of cement replacement. The ideal ratio of this replacement is around 3% to 4% by weight of fine aggregate. Higher ratios lead to stiff mixtures with low workability.

- The use of soda waste in its original sludge form is possible since its water content is uniform and as long as this content is taken into consideration in the mix design. The similar results of sludge soda waste and dry soda waste means that drying the sludge is not needed.

- To use the water content of soda waste effectively, in other words, to let the soda waste release part of its water content, the soda waste sludge should be premixed with coarse aggregate for about 2 to 3 minutes.

- Using soda waste in SCC increases the viscosity of the concrete, and reduces the bleeding and segregation amount. As the amount utilized increases the workability of the concrete decreases.

- Unlike the soda waste, the use of beer waste in the sludge form is not practical to be used in SCC, since its water content is not uniform. It is speculated that the high rate of organic content found in the beer waste sludge, the yeast, may let the fermentation process continue which may lead to a change in the chemical composition of the waste. That might be the reason behind the contradiction in the results when beer waste was used.

5.2 Recommendations for further studies

Considering the results obtained from this thesis, some recommendations for further studies are suggested below:

- In this experimental study both wastes were presumed to be used as viscosity modifying agents in SCC. Other possible uses such as dry concrete systems (zero slump concretes, roller compacted concretes), controlled low strength concrete and concrete bricks can be considered. While doing so, not only workability and strength, but also the durability of the produced products should be investigated.

- The use of soda waste together with pozzolanic materials such as fly ash and GGBFS could be considered, in order to utilize the alkaline activation property of the waste.

- To evaluate the effects of beer waste, a more enhanced work can be done. The effect of the organic materials on the chemical composition in time can be investigated by performing chemical analyses on the dry beer waste at different periods of time to define when the waste reaches a stable status. Exposing the beer waste to high temperature to eliminate the organic materials can also be considered.

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