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INVESTIGATION OF THE EFFECT OF GLASS SAND USED IN SCC ON THE BEHAVIOR OF THE SCC STRESS - STRAIN RELATIONSHIP

Serkan Etli[*1]

[1]*Department of Emergency Aid and Disaster Management, Munzur University, Tunceli, Turkey*

Abstract

Original scientific paper

Glass, who is found as a waste in nature, seems to be among the causes of fires in forest areas and landfills, especially with the increase in temperature in recent years. Within the scope of the study, waste soda glass bottles collected from waste sites and natural environment were separated by passing through 0.25-0.5 mm sieves after grinding. The self-compacting concrete (SCC) produced with this glass sand were replaced with the natural sand inside. Natural sand and glass sand were substituted in increments of 5% between 5% and 35% by volume. SCC were tested with fresh feature tests where it provides regulatory standards. Stress-strain relationships were obtained for 7- and 28-days old samples from the mixtures obtained. These relations were evaluated by comparing them with the concrete model, which is frequently used in the literature. It was observed that the resulting stress-strain relations converged well to the model chosen especially at the age of 7 days but diverged from the model used at the age of 28 days, especially in the initial part.

Keywords: *Glass sand, stress-strain relationship, waste glass, self compacting concrete.*

KYB'DE KULLANILAN CAM KUMUN KYB YÜK-DEPLASMAN İLİŞKİSİNİN DAVRANIŞI ÜZERİNDEKİ ETKİSİNİN ARAŞTIRILMASI

Özet

Orijinal bilimsel makale

Doğada atık olarak bulunan cam, özellikle son yıllarda sıcaklığın artmasıyla birlikte ormanlık alanlarda ve düzenli depolama alanlarında çıkan yangınların sebepleri arasında görünmektedir. Çalışma kapsamında atık sahalarından ve doğal ortamdan toplanan atık soda cam şişeleri öğütüldükten sonra 0.25-0.5 mm arasında eleklerden geçirilerek ayrıştırılmıştır. Bu cam kum ile üretilen kendiliğinden yerleşen beton (KYB), içindeki doğal kum ile değiştirilmiştir. Doğal kum ve cam kumu, hacimce %5 ila %35 arasında %5'lik artışlarla ikame edilmiştir. KYB, yönetmeliklerle ilgili standartları sağladığı taze özellik testleri ile test edilmiştir. Elde edilen karışımlardan 7 ve 28 günlük numunelerde gerilme-şekil değiştirme ilişkileri elde edilmiştir. Elde edilen bu ilişkiler literatürde sıklıkla kullanılan beton modeli ile karşılaştırılarak değerlendirilmiştir. Ortaya çıkan yük-deplasman ilişkilerinin özellikle 7 günlük yaşta iyi bir şekilde seçilen modele yakınsadığı ancak özellikle başlangıç kısmında 28 günlük yaşta kullanılan modelden ayrıldığı görülmüştür.

Anahtar Kelimeler: *Atık cam, cam kumu, kendiliğinden yerleşen beton, stress-deformaasyon ilişkisi.*

1 Introduction

There has been an increasing interest in the use of recycled material-based products in the construction industry, especially in the last century, to ensure sustainable green construction production and to promote production [1–6]. Concrete, which is the most preferred building material during structural production, is the most consumed man-made material for construction in the world. For 2007, it was reported that concrete production in the USA was approximately 800 million tons, and worldwide consumption was approximately 11 billion tons. In addition, it is estimated that there is an average of 1.7 tons of concrete consumption for every person living in the world [7]. Glass bottles and containers are often preferred by people for the storage and preservation of food and beverages. In addition, the containers and bottles left behind after the materials in these products are consumed are generally left to nature as household waste. In this case, the products pose a great threat to the natural environment. Especially after visiting forest areas for camping or recreational purposes, such glass-based wastes cause fires at high temperatures in the summer months when the sun is intense. Therefore, it is thought that removing such wastes from the natural environment or collecting them for recycling will have a significant impact in this context. In

[*] Corresponding author.

E-mail address: serkanetli@munzur.edu.tr (S. Etli)

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addition, as mentioned above, it is important to control the usability during the production of high consumption concrete and its derivatives and to determine the maximum glass powder content to be used, if any.

Waste glass materials produced in mixed colors not only improve the chemical stability of concrete, but also increase its durability along with moisture resistance. This shows that waste glass materials have the desired chemical composition and reactivity to be used as a binder material with high potential to provide benefits with proper use. For this potential behavior to occur, waste glass must be ground to a microscale particle size to accelerate chemical reactions in concrete and chemical reactions that can beneficially improve these properties [8–10].

In addition to this rapid superstructure formed in the construction sector, increasing concrete consumption occurs due to rapid infrastructure development. As a result of this development, the amount of natural aggregate used is increasing in parallel with the acceleration of concrete production in the world. In addition, this consumption causes the consumption of natural resources to a large extent and indirectly harms the nature. The production and consumption of sand and gravel, which accounted for 79% of the annual production from natural resources in 2010, is growing in parallel and is the most extracted natural resource worldwide with 28.6 giga tons. The purpose of use of the study, on the other hand, aims to show a method for reducing the use of these standards with the purpose of use. [11, 12]. Natural river sand used in concrete production has been included in mixtures as fine aggregate for centuries. Although the amount of sand in the world seems unlimited, considering the concrete consumption rate, it appears as a limited natural resource that can be consumed in a short time. Excessive removal of sand from its source not only causes sand pollution, but also damages aquatic ecosystems, water stress and turbidity. Worse, it harms the climate, along with a reduction in the supply of nutrients produced from water sources. Additionally, excessive sand production can aggravate damage from floods, tsunamis and storms as it accelerates the erosion of shorelines and riverbanks. On the other hand, the lowering of the water table and the supply of sand and the intrusion of salt water into the soil affect the groundwater supply and, worse, can damage river basins, bridge piers and civil infrastructures. [11, 12].

Extracting sand and then transporting it from the collection site to the construction site for production is related to the increase in greenhouse gas emissions. Due to the negative impact of this situation, the construction industry is in a general search for the use of alternative materials that can replace recycled waste glass and natural sand in the concrete to be used in the field [13]. However, the availability of plastic containers, metals and accompanying materials such as waste glass, inconsistencies in the chemical composition of different types of glass, and the difficulty of separating different colored glass are the biggest challenges in the recycling process. The use of waste glass, which has the potential to be used instead of sand in concrete, can be an attractive method for removing waste glass from nature and reducing the use of sand. Therefore, it is thought that these studies can help not only to remove natural sand, but also to reduce the amount of waste glass formed in landfills [12]. In recent years, waste glass bottles for concrete production have been recycled using recycled and various studies have been carried out to investigate the use of glass sand [14–17]. Considering the chemical composition and physical properties of crushed glass, it is obtained as a better alternative to sand to be used in concrete [15]. In addition, the presence of smooth surfaces in ground glass and relatively lower water absorption capacities than sand suggested that glass sand could improve the production properties of fresh concrete [18]. Glass sand, on the other hand, increases the chloride ion penetration resistance, but sometimes has conflicting results in the mechanical and durability properties of hardened concrete [14–16, 19–23].

In the study carried out within the scope of the article, it is aimed to facilitate the disposal of waste materials and to evaluate the appropriate uses based on glass sand production. Considering the mechanical properties of glass, it is aimed to evaluate its use as sand and particles close to sand. In this context, besides the effects of glass materials on possible natural disasters, a study was conducted to reduce the damages caused using glass materials during concrete production. Since the sand used in concrete and used in high amounts is obtained by the disposal of nature, it leads to the deterioration of the ecological environment. It is aimed to evaluate the use of waste glass as an alternative to partially reducing the use of sand in concrete. In addition, the evaluation of how glass sand affects the mechanical behavior of concrete in mechanical calculations using stress-strain curves is also presented in the study. In this context, within the scope of the article, besides the disposal of glass and derivative wastes, its effect on the matrix it is in was compared with traditional models and the evaluation of the effect on its use was presented.

Within the scope of this study, an experimental study of the use of glass sand, which is sieved in the range of 0.25-0.5 mm after grinding and sifting the soda bottles collected from nature, is presented. In the study, 7 mixtures were created, including the control mixture, by substituting glass sand and natural sand from 5% to 35% in increments of 5%. The mixtures obtained were produced as SCC (self-compacting concrete) in EFNARC [24] standards. The load-displacement behaviors of the 7- and 28-day samples were compared with the Mander [25] concrete model accepted in the literature and the results were examined. A brief flowchart of the workflow was shown in the Figure 1.

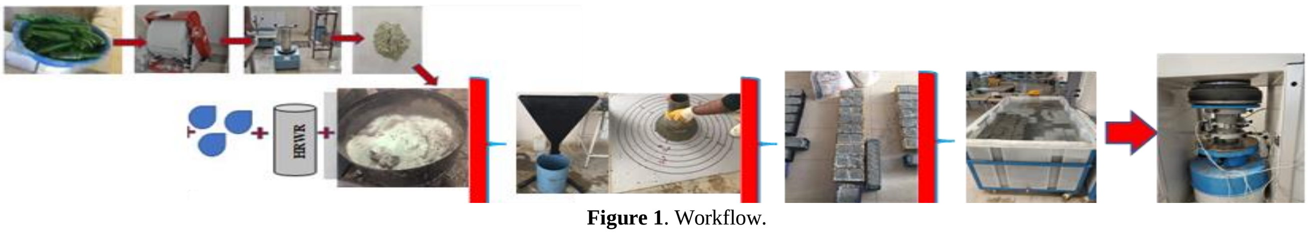

Figure 1. Workflow.

2 Materials and Experimental Campaign

Information on the materials used in the mixtures produced within the scope of the study and the methodological processes used in their proportions are included in this section under sub-headings. A brief flowchart of the study methodology was shown in Figure 1. In the mixtures produced, waste glass ground with natural sand was replaced by 5% between 5% and 35% by volume. Binder dosages with a total binder content of 600 kg/m3 were used in each mixture group. In the mixtures produced, 0%, 5%, 10%, 15%, 20%, 25%, 30% and 35% glass sand (0.25-0.5 mm) by volume was used instead of natural sand (0-4 mm). As a result, a total of 7 mixtures were produced, including those substituted with ground glass, within the scope of the study. In the group mixtures produced, 100×100×100 mm^3 cube samples were produced for mechanical testing for each mixture. Mechanical properties tested at 7 and 28 days old. Meanwhile, charge-displacement relationships were recorded. The Mander [25] concrete model, which is widely used in the literature, was used with the obtained data.

2.1 Materials

Within the scope of the study, CEM-I 42.5R Portland cement was used as a binder in the production of the mixtures. Natural washed sand and coarse aggregate obtained from the river in Tunceli province were used in the mixtures. Chemical properties of ground glass aggregate and cement were given in Table 1. Glass bottles as frosted glass aggregate, especially soda/mineral water bottles recycled as domestic waste in nature, were collected and then these bottles were ground and used as glass aggregate. Sieve analyzes for natural sand and medium aggregate obtained by sieving were shown in Figure 2.

Table 1. Chemical composition of Portland Cement and glass powder dust.

Chemical composition (%)	Portland Cement	Glass sand (0.25-0.5 mm)
SiO_2	19.84	70.85
Al_2O_3	3.75	0.85
Fe_2O_3	4.15	0.23
CaO	63.87	8.84
MgO	3.15	3.8
K_2O	0.81	0.24
Na_2O	0.41	14.41
SO_3	3.15	0.23
P_2O_5	-----	0.55
Loss of ignition	0.87	-----
Blaine (cm^2/g)	3260	-----

In addition, to obtain the required workability capacity of the mixtures produced as SCC, the superplasticizer should be used in sufficient amount with low water/binder ratio in the mixture. For this purpose, a polycarboxylate ether-based chemical additive (HRWRA), which reduces water at a high rate, was used. In addition, it is aimed to provide the desired homogeneity in the mixtures produced and to have a high fluidity capacity. The specific gravity values used for cement, natural sand, coarse aggregate, glass powder and HRWR, which are the materials used in the mixtures produced as SCC, were calculated as 3.1, 2.668, 2.664, 2.523 and 1.04, respectively.

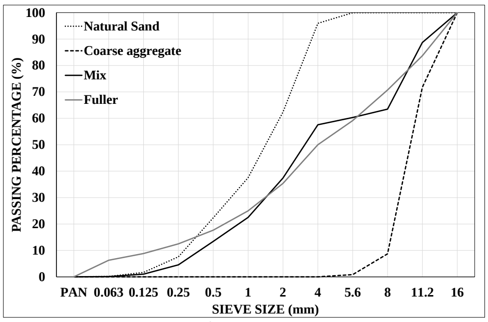

Figure 2. Sieve analysis of natural sand and coarse aggregate.

2.2 Mix Design

The SCCs produced within the scope of the study were produced homogeneously with the help of a standard mortar mixer meeting the current standard EFNARC [24] requirements until the dry mix components were prepared, and then the total homogeneity of the fresh mix was observed. As given in Table 2, the water/binder (w/b) ratio was used in the mixtures at a constant value of 0.38.

While preparing the SCC mixtures, aggregate, glass sand and cement were mixed dry for 1 minute at the mixing ratios determined during the design (Figure 3a). Then, 1/3 of the mixing water was mixed with the HRWR calculated in the SCC design and added to the dry mixture obtained in the first step. In the case of this mixture, it was mixed for 1 more minute. Afterwards, the remaining mixing water (2/3 of the mixing water) was added, and the concrete mixer was operated for 1 more minute (Figure 3b). The produced fresh SCC mixtures were mixed for 1 more minute after resting for 1 minute. The preparation time of the mixture in the mixer was 5 minutes in total. The amounts of materials used in the design of SCC mixtures are given in Table 2. "SCCGPx" name format was used in naming the mixtures. "GPx" is used in the nomenclature of the mixture and "x" indicates the volume substitution ratio between glass sand and natural sand. Compliance with the SCC classification of the mixtures prepared using the EFNARC [24] standard was tested in the laboratory by slump flow test and V-funnel test (Figure 3c and d).

Table 2. Mix design of SCCs.

Mix ID	Cement (kg/m^3)	Glass Sand (kg/m^3)	Water (kg/m^3)	Natural Sand (kg/m^3)	Coarse Aggregate (kg/m^3)	HRWR (kg/m^3)
SCCGP0	600	0.00	228.00	970.35	577.02	9
SCCGP5	600	48.52	228.00	921.83	574.09	9
SCCGP10	600	97.04	228.00	873.32	571.43	9
SCCGP15	600	145.55	228.00	824.80	568.50	9
SCCGP20	600	194.07	228.00	776.28	565.83	9
SCCGP25	600	242.59	228.00	727.76	562.90	9
SCCGP30	600	291.11	228.00	679.25	560.24	9
SCCGP35	600	339.62	228.00	630.73	557.58	9

Figure 3. Laboratory fresh mixing, workability testing stages and curing.

In the hardened concrete tests, 48 samples produced from SCC mixtures as cubes were used. In fresh concrete tests, these cube samples were produced from mixes produced as SCC in accordance with EFNARC [24]. Cube samples were produced by placing them in molds of 100×100×100 mm^3 made of fiberglass material. Axial pressure tests were carried out on the samples obtained with these cubic molds (Figure 3e). Meanwhile, charge-displacement relations were obtained. Concrete samples were removed from the molds 24 hours after they were placed in the molds and cured in 28-day tanks at 20 ± 2 °C with lime water (Figure 3f). Although each experiment consisted of 3 samples for each mixture, the results were calculated as the average of these three samples.

3 Results and Discussion

3.1 Fresh State Test Results

In Figure 4, the flowing diameter and V-cone results from the fresh concrete test results made in the mixtures produced within the scope of the study are given. The control mix meets the requirements of the SF3 class Slump-flow class according to EFNARC [24] (≥ 760 mm, ≤ 500 mm). In addition, the blends of SCCGP5, SCCGP10 and SCCGP15 meet the requirements of the SF2 class Slump-flow class (≥ 660 mm, ≤ 750 mm), while the remaining mixtures meet the requirements of the SF1 class Slump-flow class (≥ 550 mm, ≤ 650 mm). It was determined that the SCC reached a lower flow diameter as the glass sand replacement ratio increased (Figure 4).

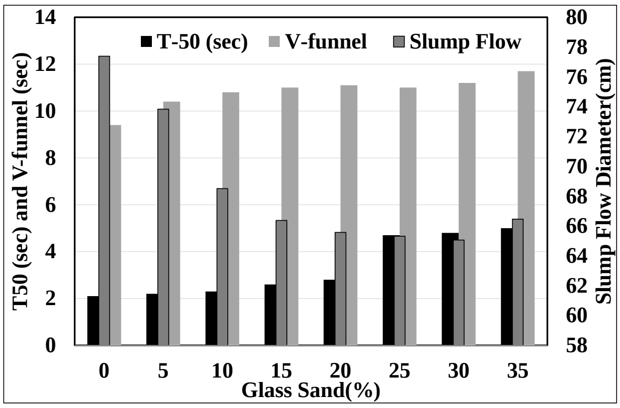

Figure 4. Workability testing results.

As the glass sand replacement rate used in the flow times measured with the V-funnel increases, an increase in the time is observed. On the other hand, when the v-funnel classes determined by EFNARC [24] were examined, it was determined that all mixtures were V-funnel class VS2/ VF2 (≥ 9 s, ≤ 25 s). In addition, T50 times >2 s indicate that the mixtures fit this class (Figure 4).

3.2 Mander Concrete Model

Mander et al. [25], the theoretical stress-strain model developed for confined concrete is also valid for unconfined concrete if the confining effect is not taken into account (Figure 5).

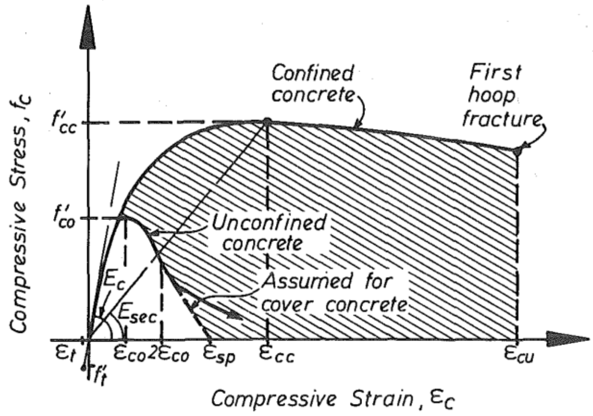

Figure 5. Stress-Strain model proposed for monotonic loading of confined and unconfined concrete [25].

The Mander [25] model for confined concrete is discussed in detail in literature. For the unconfined concrete, the effective confinement pressure for the confined concrete model is f_e=0 and λ_c=1 from Equation 1. Since λ_c=1, the values f_{cc}=f_{co} and ε_{cc}=ε_{co} are obtained from Equation 2 and Equation 3. The equations for the curve are given below.

$$\lambda_c = \left[2.254 + \sqrt{\frac{7.94 \times f_e}{f_{co}}} - \frac{2 \times f_e}{f_{co}} - 1.254\right] \quad \varepsilon_c > \varepsilon_{cu} \quad (1)$$

$$f_{cc} = f_{co} \times \lambda_c \quad \varepsilon_c > \varepsilon_{cu} \quad (2)$$

$$\varepsilon_{cc} = \varepsilon_{co} \times [1 + 5 \times (\lambda_c - 1)] \quad (3)$$

The function definitions of the curve are evaluated in two parts. The first part is given in Equation 8 of the curve in the part defined for the pre-maximum stress point. The boundary condition for this curve is given as ($\varepsilon_c \le 2 \times \varepsilon_{co}$). The other curve part is given in Equation 9. The conditions for this part are given with ($2 \times \varepsilon_{co} < \varepsilon_c \le \varepsilon_{c'u}$). The equations for the curves of unconfined concrete are given below.

$$E_c = 5000 \times \sqrt{f_c} \quad (4)$$

$$E_{sec} = \frac{f_{cc}}{\varepsilon_{cc}} \quad (5)$$

$$r = \frac{E_c}{E_c - E_{sec}} \quad (6)$$

$$x = \frac{\varepsilon_c}{\varepsilon_{co}} \quad (7)$$

$$\sigma_c = \frac{f_{co} \times x \times r}{r - 1 + 2^r} \quad (8)$$

$$\sigma_c = f_{co} \times \left(\frac{2 \times r}{r - 1 + 2^r}\right) \times \left(1 - \frac{\varepsilon_c - 2 \times \varepsilon_{co}}{\varepsilon_{cu} - 2 \times \varepsilon_{co}}\right) \quad (9)$$

Here, ε_{cc} is the deformation value at which the wrapped concrete reaches maximum stress; ε_{cu} is the final unit deformation in unconfined concrete after pouring the shell concrete; f_{cc} is the compressive strength of the wrapped concrete; f_{co}, compressive strength of uncoated concrete; E_{sec} is the secant modulus of the concrete section.

In Figure 5, the use of the Mander [25] concrete model for unconfined concrete and confined concrete is given comparatively. In the unconfined concrete model, the unit strain value (ε_{co}) at which the concrete reaches the maximum stress is taken as 0.002. The unconfined concrete curve reaches its final strain linearly, assuming that the shell concrete is poured after $2\varepsilon_{co}$. Considering that the shell concrete is not poured, the unit strain will increase a little more.

3.3 Hardened Test Results

The mechanical test results of cube samples with dimensions of 100×100×100 mm^3 obtained within the scope of the study are presented in this section. In the study, samples from two different age groups and 8 different mixtures were tested. 7 mixtures obtained by replacing the natural sand volume with a control mixture of glass sand in the range of 5-35% were examined within the scope of the study. First group samples and second group samples were left in the curing tank to cure at the same time. The first batch of samples were taken from the tanks at 7-days of age and tested. The second group was taken from the curing tanks and tested at 28 days of age. The load displacement values of these samples were obtained by testing them under axial pressure using a test device with a load capacity of 3000 kN. 7-day results were shown in Figure 6 and 28-day samples were shown in Figure 7. While axial strain is shown on the horizontal axis in the graphs, stresses are obtained on the vertical axis. The stress-strain results of 3 samples from each test mixture were used while plotting the graphs. The mean curves obtained are the polynomial mean curves of 3 samples obtained using the MATLAB [26] program. The resulting AVE curve obtained and presented in the graphs are mathematical functional curves produced using experimentally obtained stress-strain curves. The maximum compressive strength of this curve, defined as AVE, was evaluated as the average compressive strength for these three curves. For the Mander [25] concrete model for unconfined concrete in the graphics, this value is used as the compressive strength value, ie f_{cc} (Figure 6 and 7). The compressive strength capacities of each sample are shown with the symbol "C" on the graphs (Figure 6 and 7). In addition, the mixing curves of the Mander [25] concrete model are presented in the graphs for each mixture using the capacity of the average curve obtained.

In general, the results of all mixture samples obtained for 7 days of age ranged from 65 to 73 MPa. On the basis of the samples, the lowest compressive strength was obtained from 35% by volume glass sand replacement, and the highest compressive strength was obtained from 30% volume glass sand replacement. It is also stated in other studies in the literature that some inconsistencies were observed in the results obtained. In the case of 10% to 25% glass sand replacement, the mean values of the mixture groups in the mean curves fitting the resulting stress-strain curves are almost the same. Moreover, results were calculated as 68 MPa. With 30% and 35% glass sand substitution by volume, the values were calculated as 67 and 64 MPa, respectively, as a result of this fitted average curve (Figure 6).

The results of all mixture samples obtained for 28 days of age ranged from 65 to 80 MPa. Based on the sample, the lowest compressive strength was obtained from 35% by volume glass sand replacement, and the highest compressive strength was obtained from 5% volume glass sand replacement. Within the scope of the study, which includes ground glass with different low fineness values examined in the literature, a similar change is observed in the materials defined as glass sand [27–29]. It was seen that the size of the glass sand used has a more specific surface than the extracted sand. For this reason, more cement meets the specific surface in the concretes produced. This can cause a reduction in compressive strength. In addition, the fact that the compressive strength of the glass sand used is weaker than the cement paste was predicted as another negative effect. In the case of 10% to 25% glass sand change, the mean values of the mixture groups in the mean curves matching the resulting stress-strain curves are almost the same. In addition, the average results were calculated as 68 MPa. With 30% and 35% glass sand substitution by volume, the values were calculated as 69 and 68 MPa, respectively, because of this fitted average curve (Figure 7).

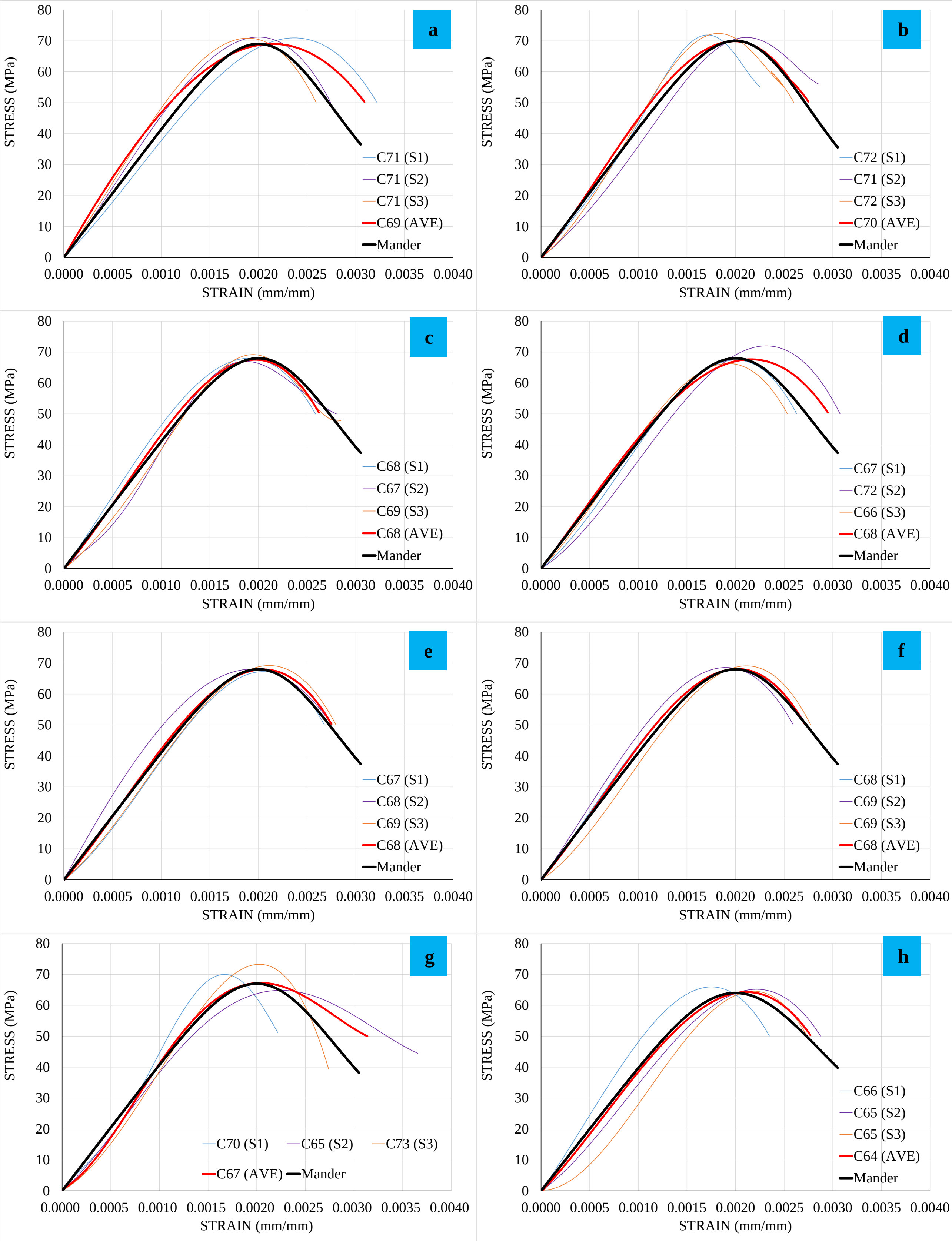

Figure 6. SCCs stress-strain results for the replacement level of a)%0, b)%5, c)%10, d)%15, e)%20, f)%25, g)%30 and h)%35 at 7-day age.

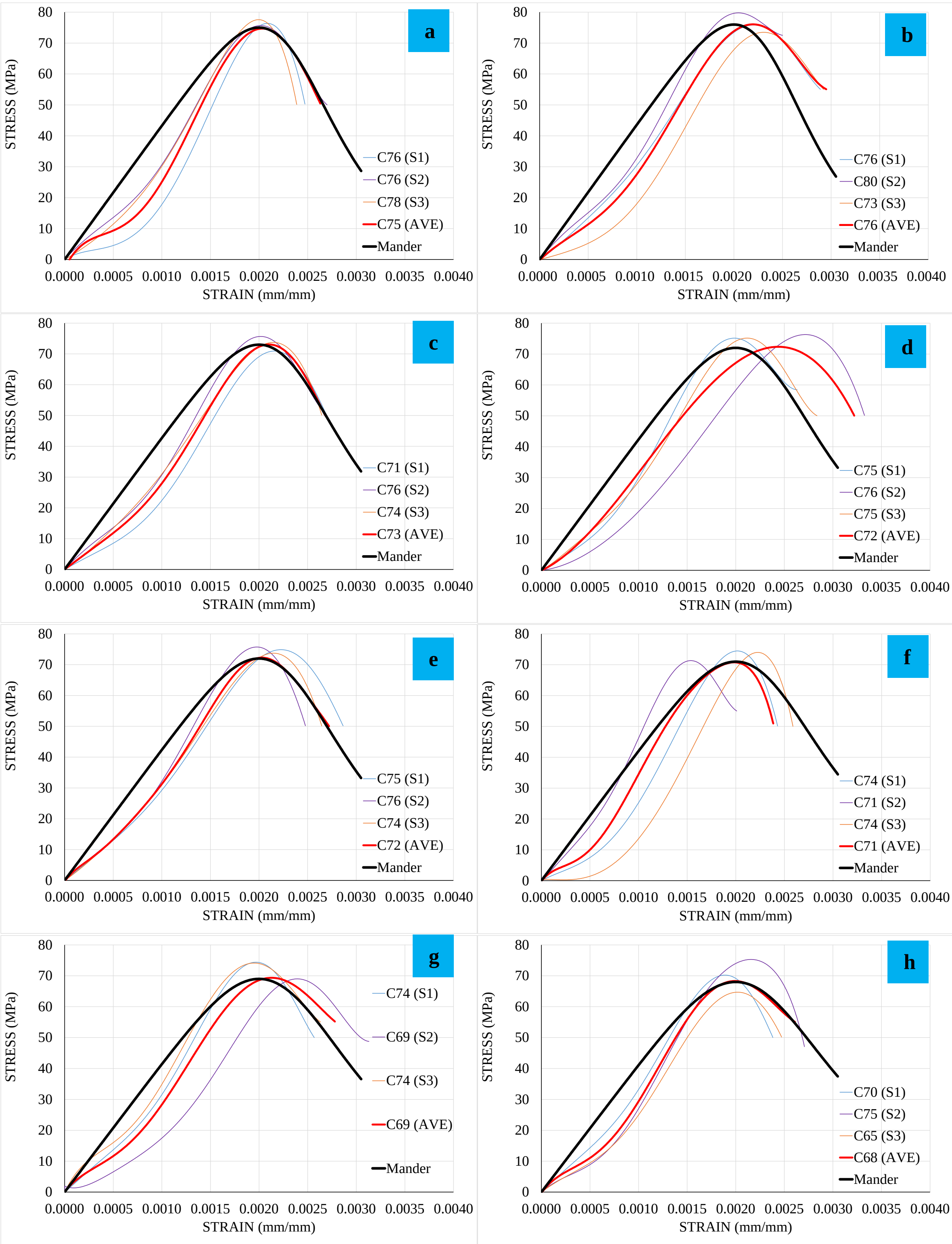

Figure 7. SCCs stress-strain results for the replacement level of a)%0, b)%5, c)%10, d)%15, e)%20, f)%25, g)%30 and h)%35 at 28-day age.

4 Conclusion

Within the scope of the study, waste soda glass bottles collected from waste sites and natural environment were separated by passing through 0.25-0.5 mm sieves after grinding. This glass sand produced by volume has replaced the natural sand in SCC. Natural sand and glass sand were substituted in increments of 5% between 5% and 35% by volume. SCC has been tested with new feature tests where it meets regulatory standards. Stress-strain relationships were obtained for 7- and 28-days age samples from the mixtures obtained. These relationships were evaluated by comparing them with the Mander concrete model, which is frequently used in the literature. The results obtained are summarized below.

- It is seen that the load-displacement relations are in good harmony with the Mander concrete model, especially in the 7-day samples.

- Although the initial curves of the Mander concrete model did not match with the initial curves of the 28-day samples, it was observed that the Mander model used in particular approached the maximum compressive strength as it converged.
- The replacement of natural sand with 5% glass sand by volume slightly increased the compressive strength.
- Replacing natural sand with 10% to 20% by volume glass sand resulted in a slight reduction in compressive strength. Although the decrease in the average compressive strengths obtained is the same, it is seen that the stress-strain behaviors that occur are different from each other on the basis of the sample.
- The most significant compressive strength changes occur at 30-35% glass sand replacement. It is possible that the effectiveness of the specific surface area increased by glass sand with low compressive strength is even more effective with increased glass sand.

Declaration

Ethics committee approval is not required.

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