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FUNDAMENTAL INVESTIGATION OF RECYCLED CONCRETE USING PAPER SLUDGE ASH AND SILICA FUME

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Abstract

Waste management and recycling of wastages play an important role in having a sustainable city or eco-city. Rapid increasing population in some cities of the world and especially in developing countries cause a different kind of pollution such as air, water, noise, visual, etc. Wastages are directly associated with city contamination. Useful policies for recycling waste can reduce pollution and boost the economy of a country. This study investigates the influence of recycled concrete aggregate (RCA), Silica fume (SF), and paper sludge ash (PSA) on the workability, compressive strength, and acoustic emission behavior of concrete. 5 and 10% of cement were replaced by PSA and silica fume and 10 and 20% of coarse aggregate was replaced by the recycled aggregate. PSA and SF improved the Strength, and acoustic emission behaviors of concrete, moreover, the recycled aggregate also improved the properties of concrete.

Keywords

Paper Sludge Ash, Silica Fume, Recycled Aggregate, Workability, Strength, Acoustic Emission Behavior

1. Introduction

Portland cement concrete is a construction material that is the most used material after water in the world.

Annually, a huge amount of waste concrete is generated due to the demolition and reconstruction process. It is estimated that 900 million tons of waste concrete are generated in the USA, India, Europe, and Japan. Most of this waste is trashed and disposed of in landfills which creates environmental problems (Yadhu & Devi, 2015).

Recycled Concrete Aggregate (RCA) is a concrete material that is produced by modification of waste concrete, this material is not widely used as aggregate due to its higher water absorption and lowers specific gravity, consequently, strength and durability are negatively affected. Different kind of substance is used as an admixture or as partial cement substituents to enhance strength and durability of recycled aggregate concrete such as Silica fume, fly ash, steel fiber, etc. (Buck, 1977), (Yang, Du, & Bao, 2011) (Çakır & Sofyanlı, 2015).

Waste paper sludge is another material that can be recycled like other pozzolans such as ash fly ash (Luga, Paja, & Atis, 2017), after incinerating paper sludge at approximately 800 °C, ash will be produced that have reactive silica and can chemically react with cement and can improve some properties of concrete (Sajad, 2013).

Silica fume (SF) is an ultrafine by-product of silicon processing industries. It has an amorphous shape and highly reactive silica. Silica fume has a surface area of 15-25 m²/gram. This by-product increases the Si/Ca ratio in the binder which improves the permeability of the paste and hence, increase the strength and durability of concrete (Chakravarthy & Ali, 2015). This research will further study the by-product by conducting an Acoustic emission behavior test on concrete containing 5 and 10% silica fume.

Each of the binder (SF and PSA) need to be used together with RCA to study their influence on some properties of recycled aggregate concrete. moreover, each of the binders and recycled

aggregate also need to be used separately to acknowledge their single effect on the properties of Portland cement concrete.

1.1 Significance of the Research

- Enhance the tendency of people to utilize paper waste and concrete waste effectively to reduce disposal amount for landfill.
- Energy and heat can be produced while burning paper sludge, and by secondary ignition and incineration at a temperature of about 800, it can be converted to pozzolan, which can be partially replaced with cement.
- Consequently, the rectification and exploitation of both wastes have economic and environmental advantages for the world.

1.2 Objectives

The following properties of concrete with different percentages of paper sludge ash, silica fume, and recycled aggregate are investigated and then compared with the conventional or reference concrete.

- Workability
- Compressive Strength
- Acoustic Emission Behavior

2. Materials

The materials which were used for the making of the samples consisted of the binders, aggregate, water and admixture. The specifications of the materials are explained as follow:

2.1 Binders

Ordinary Portland cement (OPC), Paper sludge ash, and silica fume with specific gravities of 3.15, 2.43, and 2.22 respectively, were used as binders for making the samples.

SEM (scanning electron microscope) was used to find the surface topography of a material. Both the materials have an amorphous molecular structure.

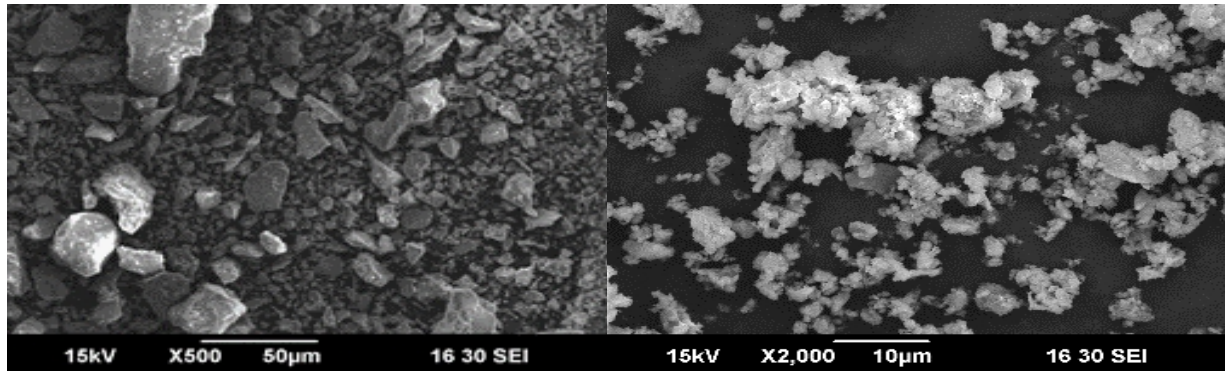


Figure 1: SEM of OPC

Figure 2: SEM of PSA

XRF (X-ray fluorescence) was conducted on each of the binders to find chemical compositions and the result is shown in Table 1.

Table 1: XRF of the Cement, Paper Sludge Ash and Silica Fume

| Oxides | OPC (%) | PSA (%) | Silica Fume (%) |
|--------------------------------|---------|---------|-----------------|
| Na ₂ O | 0.217 | 0.372 | 0.213 |
| MgO | 0.964 | 2.968 | 0.390 |
| Al ₂ O ₃ | 4.234 | 12.282 | 0.237 |
| SiO ₂ | 17.899 | 16.906 | 96.536 |
| P ₂ O ₅ | 0.174 | 1.162 | 0.082 |
| SO ₃ | 3.009 | 2.412 | 0.223 |
| K ₂ O | 0.517 | 0.314 | 0.837 |
| CaO | 69.045 | 61.068 | 0.222 |
| TiO ₂ | 0.279 | 0.615 | 1.079 |
| MnO | 0.076 | n/a | n/a |
| Fe ₂ O ₃ | 3.411 | 1.611 | 0.100 |
| CuO | 0.041 | 0.063 | 0.017 |
| ZnO | 0.070 | 0.068 | n/a |
| SrO | 0.048 | 0.039 | n/a |
| ZrO ₂ | 0.017 | 0.016 | n/a |

2.2 Aggregate

Aggregate is the important component of concrete. It has a major role in the specification of the properties and quality of concrete. In this experiment, around 80% of the mass of the concrete was occupied by the aggregate. Aggregate is categorized as fine and coarse aggregate and each of them is described as below.

2.2.1 Fine aggregate

Sea sand was used as fine aggregate with oven-dry density and water absorption of 2.5 and 2.87 respectively

Table 2: Size Distribution of Fine Aggregate

| Size of sieve openings (mm) | Passing (%) |
|-----------------------------|-------------|
| 9.5 | 100 |
| 4.75 | 100 |
| 2.36 | 98.42 |
| 1.18 | 81.82 |
| 0.6 | 52.26 |
| 0.3 | 24.74 |
| 0.15 | 7.1 |

2.2.2 Coarse aggregate

Crushed stones and recycled aggregates were used as coarse aggregate. Specific gravity and water absorption are shown in Table 3 below.

Table 3: Properties of Coarse Aggregate

| Physical property | Crushed stone | Recycled aggregate |
|---------------------------------------|---------------|--------------------|
| Oven-dry density (g/cm ³) | 3.02 | 2.76 |
| Water absorption | 0.56 | 2.4 |

The pulsed power apparatus was used to produce recycled aggregate. A high grade of recycled aggregate can be discharged when this apparatus is used (Shigeishi, et al., 2013). The recycled coarse aggregate was obtained by applying energy of E/N=6.4 kJ per pulse at a capacitance of 0.8 μF and the applied voltage of 400 kV satisfied the oven-dry density criterion and the water absorption coefficient criterion when using applied energy of 384 kJ. Thus, the frequency of pulsed discharge was 60 times underwater. consequently, high grade recycled aggregate produced which satisfied JIS regulation class H (A 5021) for high grade recycled concrete aggregate, as this regulation require oven-dry density for recycled aggregate to be at least 2.5 gr/cm³ and maximum water of absorption of 3%.



Figure 3: Recycled Aggregate

Table 4: Size Distribution of Coarse Aggregate

| Size of sieve opening (mm) | Passing (%) | |
|----------------------------|---------------|--------------------|
| | Crushed stone | Recycled aggregate |
| 25 | 100 | 100 |
| 20 | 96.31 | 100 |
| 15 | 84.07 | 94.66 |
| 10 | 27.74 | 56.71 |
| 5 | 0.71 | 0.42 |
| 2.5 | 0.04 | 0.05 |
| 1.2 | 0.035 | 0.03 |

3. Procedure and Experiment

The procedure of the sample preparation and conduction of the experiment are described in the following subsections.

3.1 Mix proportion

The w/c ratio was maintained to 0.55, while sand/ aggregate was kept to 0.48. 15 types of samples were prepared. The mix proportion is described in Table 5. To study the effect of paper sludge ash on the properties of concrete, it was replaced with 5 and 10 percent of cement, and the same amount of cement was replaced by another pozzolan which is silica fume, which is a widely used material in the world to enhance some characteristic of concrete. To investigate the influence of recycled aggregate on properties of concrete samples, RCA replaced 10 and 20 percent of natural aggregates. Polycarboxylate superplasticizer was used as a water-reducing agent, and to increase the flowability of concrete, the amount of usage was kept the same (1 percent of the weight of cement) to all sample types.

Table 5: Mix Proportion

| No | Sample name | Cement kg/m ³ | PSA kg/m ³ | Silica fume kg/m ³ | Fine aggregate kg/m ³ | Coarse aggregate kg/m ³ | RCA kg/m ³ | Water kg/m ³ |
|----|-------------|-----------------------------|--------------------------|-------------------------------------|--|--|--------------------------|----------------------------|
| 1 | CON | 318 | 0 | 0 | 841 | 1070.00 | 0 | 175.00 |
| 2 | CA5 | 300.50 | 15.82 | 0 | 841 | 1070.00 | 0 | 173.97 |
| 3 | CS5 | 299.90 | 0 | 15.78 | 841 | 1070.00 | 0 | 173.63 |
| 4 | CA10 | 283.20 | 31.47 | 0 | 841 | 1070.00 | 0 | 173.07 |
| 5 | CS10 | 281.90 | 0 | 31.32 | 841 | 1070.00 | 0 | 172.27 |
| 6 | 10RC | 318 | 0 | 0 | 841 | 956.00 | 106.00 | 175.00 |
| 7 | 10RA5 | 300.50 | 15.82 | 0 | 841 | 956.00 | 106.00 | 173.97 |
| 8 | 10RS5 | 299.90 | 0 | 15.78 | 841 | 956.00 | 106.00 | 173.63 |
| 9 | 10RA10 | 283.20 | 31.47 | 0 | 841 | 956.00 | 106.00 | 173.07 |
| 10 | 10RS10 | 281.90 | 0 | 31.32 | 841 | 956.00 | 106.00 | 172.27 |
| 11 | 20RC | 318 | 0 | 0 | 841 | 842.00 | 212.00 | 175.00 |
| 12 | 20RA5 | 300.50 | 15.82 | 0 | 841 | 842.00 | 212.00 | 173.97 |
| 13 | 20RS5 | 299.90 | 0 | 15.78 | 841 | 842.00 | 212.00 | 173.63 |
| 14 | 20RA10 | 283.20 | 31.47 | 0 | 841 | 842.00 | 212.00 | 173.07 |
| 15 | 20RS10 | 281.90 | 0 | 31.32 | 841 | 842.00 | 212.00 | 172.27 |

3.2 Mixing

A concrete mixer was used to mix the materials. At first OPC, the fine and coarse aggregate was blended for 1 minute and after adding water and the superplasticizer, they were mixed for 1.5 minutes. But in the case of using PSA and silica fume, cement was first blended with sand, then for effective mixing, the cement substituents were poured in different points and blended for 1 minute. Afterward, coarse aggregate and then water was added to the mixer for mixing.



Figure 4: *Slump Test and Samples After Casting in Molds*

3.3 Slump test, specimen casting and curing

The slump test was conducted according to JIS A 1101 to study the workability or consistency of fresh concrete. A cone with a height of 30 cm, with a bottom diameter of 20 cm and an upper 10 cm was used. For each slump test, cone was filled by mortar in 3 layers and each layer was temped 25 times by a 16 mm rod. Afterward, the cone was carefully removed and the height difference is measured as a slump. All the samples were cylindrical, with a dimension of 100 mm diameter and 200 mm height. The molds were removed after 24 hours and samples were immersed in water for curing at 18-22 °C temperature until the day of their testing.

3.4 Compression Test

The compressive test was carried out on hardened concrete samples to find compression strength. Loads were applied on each of the samples until their failure, and the peak loads were then recorded. This test was performed on all 150 cylindrical samples (100 mm*200 mm) after 28 and 56 days of curing.

3.5 Acoustic Emission (AE) Behavior test

An AE(Acoustic Emission) sensor was attached to each of the samples during the compressive strength test. Due to the compression, stresses occurred inside the samples. The micro-cracks which were produced by the stresses emitted sound waves with different intensities. Above 40 decibels acoustics or elastic wave were considered to be produced by those cracks are called acoustic emission (and abbreviated as AE). AE waves propagate through concrete and can be detected on a surface by an AE sensor, which turns the vibrations into an electrical signal. The propagation of fracture sound was originally referred to AE, since it is acoustic and audible (Ohtsu, 1995).

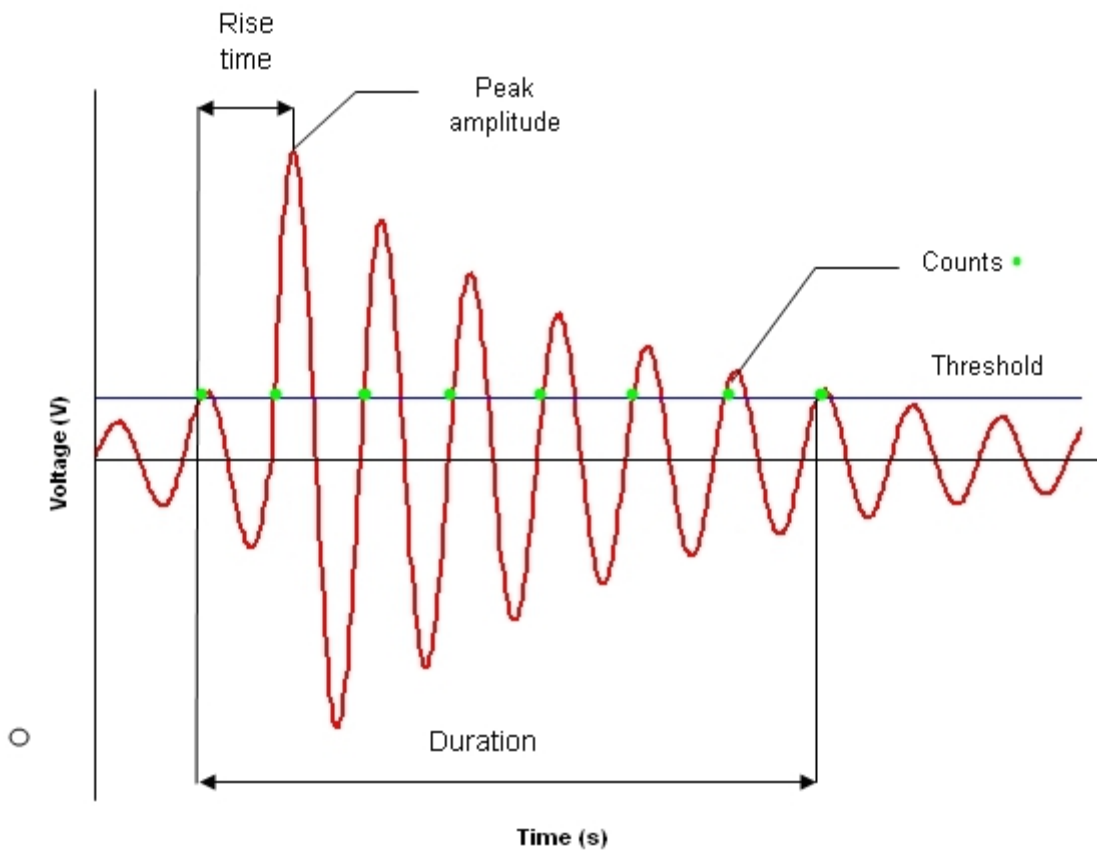


Figure 5: Parameters of Acoustic Emission Waveform(Wikimedia Commons contributors,2020)

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from <https://commons.wikimedia.org/w/index.php?title=File:Figure5.jpg&oldid=464969826>)

4. Result and Discussion

The result of the workability, 28 and 56-day compressive strength and acoustic emission behavior of each type of samples are described as follow:

4.1 Workability

The workability of concrete was increased with the 5% silica fume but slightly decreased with the 5% PSA. Both the 10% PSA and 10% silica fume significantly decreased the slump of concrete. The 10 and 20% RCA improved the workability of the samples. The 5% silica fume didn't decrease the flow rate of the 10 and 20% recycled concrete but the workability of the samples was notably decreased with PSA and 10% silica fume concrete.

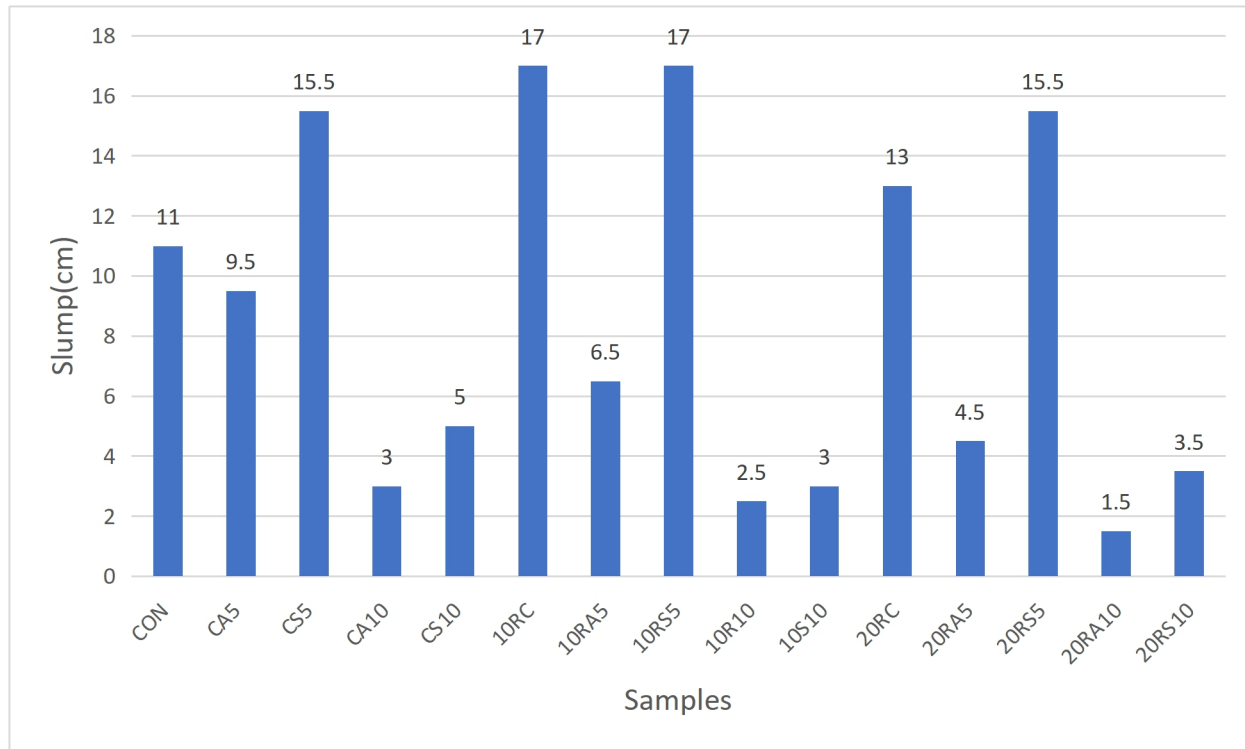


Figure 6: Slump Rate of the Concrete Samples

4.2 Compressive Strength

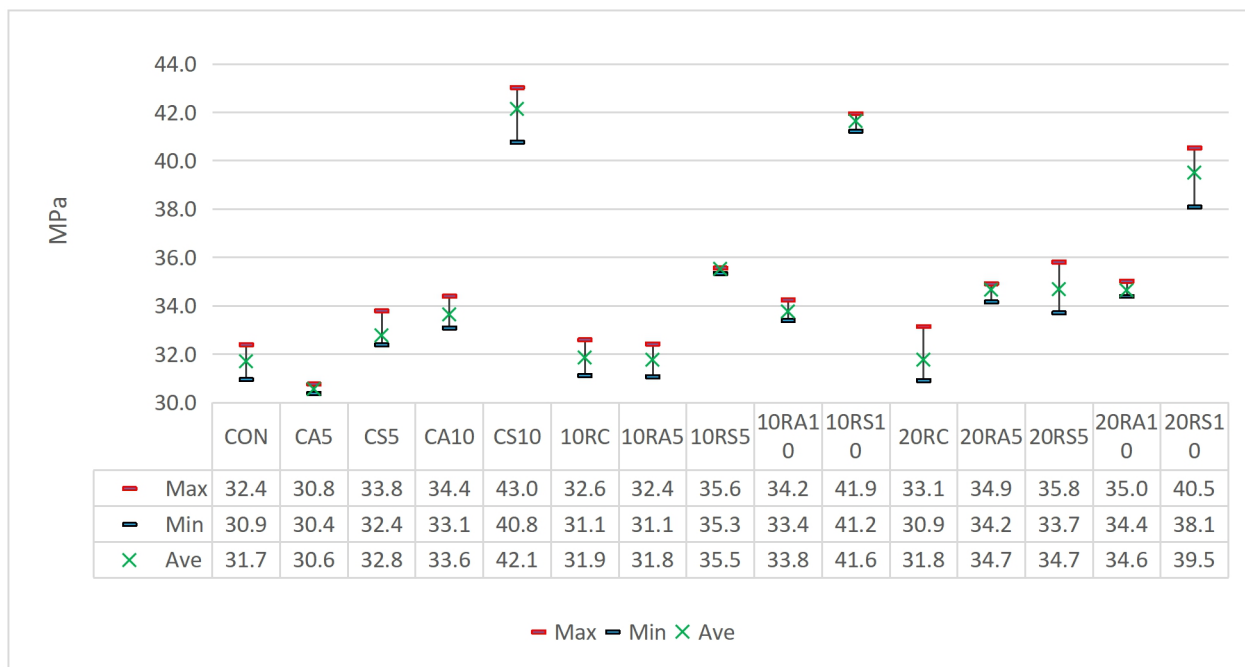


Figure 7: The 28-Day Compressive Strength

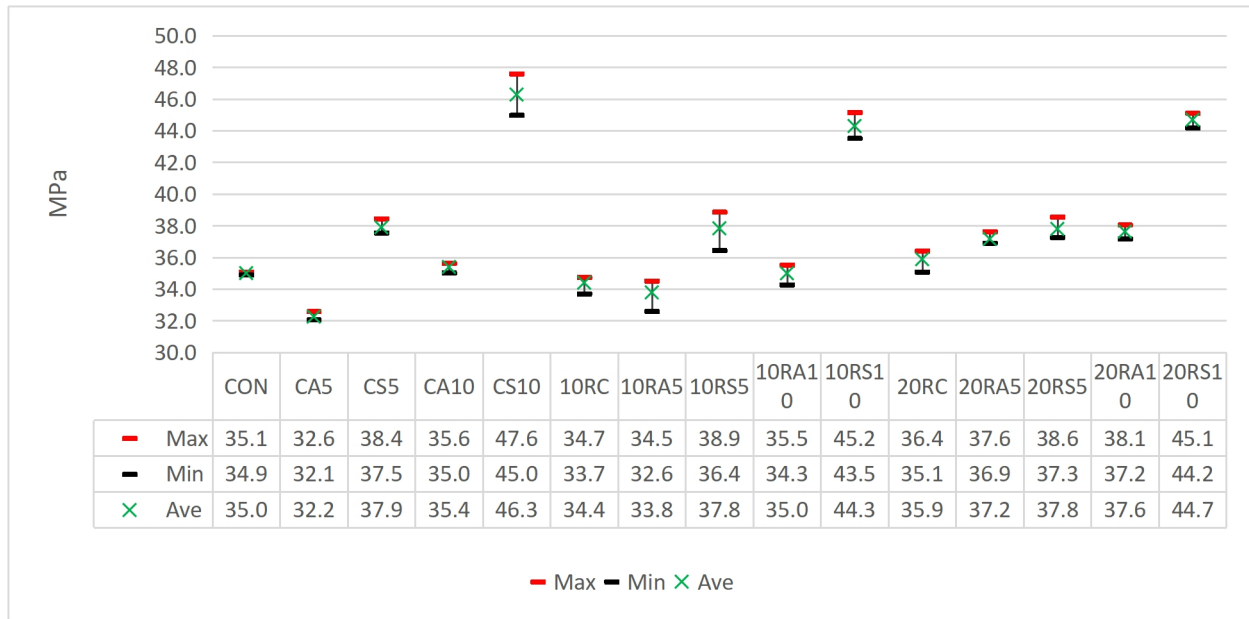


Figure 8: The 56-day compressive strength

The figures show the compressive strength of the samples after 28 and 56 days of curing. Three samples of each type of mixes were chosen for the calculation. Maximum, minimum and average strengths are shown on the charts and an average value is accepted as compressive strength for each type of sample.

Both the silica fume and the PSA increased the 28 and 56-day compressive strength. It can be said that pozzolanic reaction between ingredients of the PSA, the SF and the OPC. From the figures, it can be understood that there wasn't any significant decrease in compressive strength when recycled aggregate was used, but on the other hand, the 20% RCA increased the 56-day strength. This may be due to previously attached mortar on the surface of the RCA which helped to strengthen the bond between the cement and the RCA. Both the SF and the PSA improved the strength of the RCA concrete, especially, when they were used with the 20% recycled aggregated concrete.

4.3 Acoustic Emission (AE) Behavior

Hits vs stress diagrams of the concrete samples were drawn to study the robustness of the samples. Hits which are the accumulation of acoustic data that exceed the threshold were achieved throughout the loading process. Generally, sound concrete has low numbers of AE hits at the initial stage of stress production and the amount exceeds at the final stage. Figure 9 shows the relation between AE hits and stress level during compression loading for all types of concretes. There is no

significant difference in AE behavior between conventional concrete, silica fume concrete and both the 10% and 20% RCA concrete. AE hits were found to be consistently low at the beginning of loading and were higher when the stress reached to around 100%. Moreover, AE activity and number of cumulative hits were lower in the PSA concrete, this indicates to the robustness of this kind of concrete.

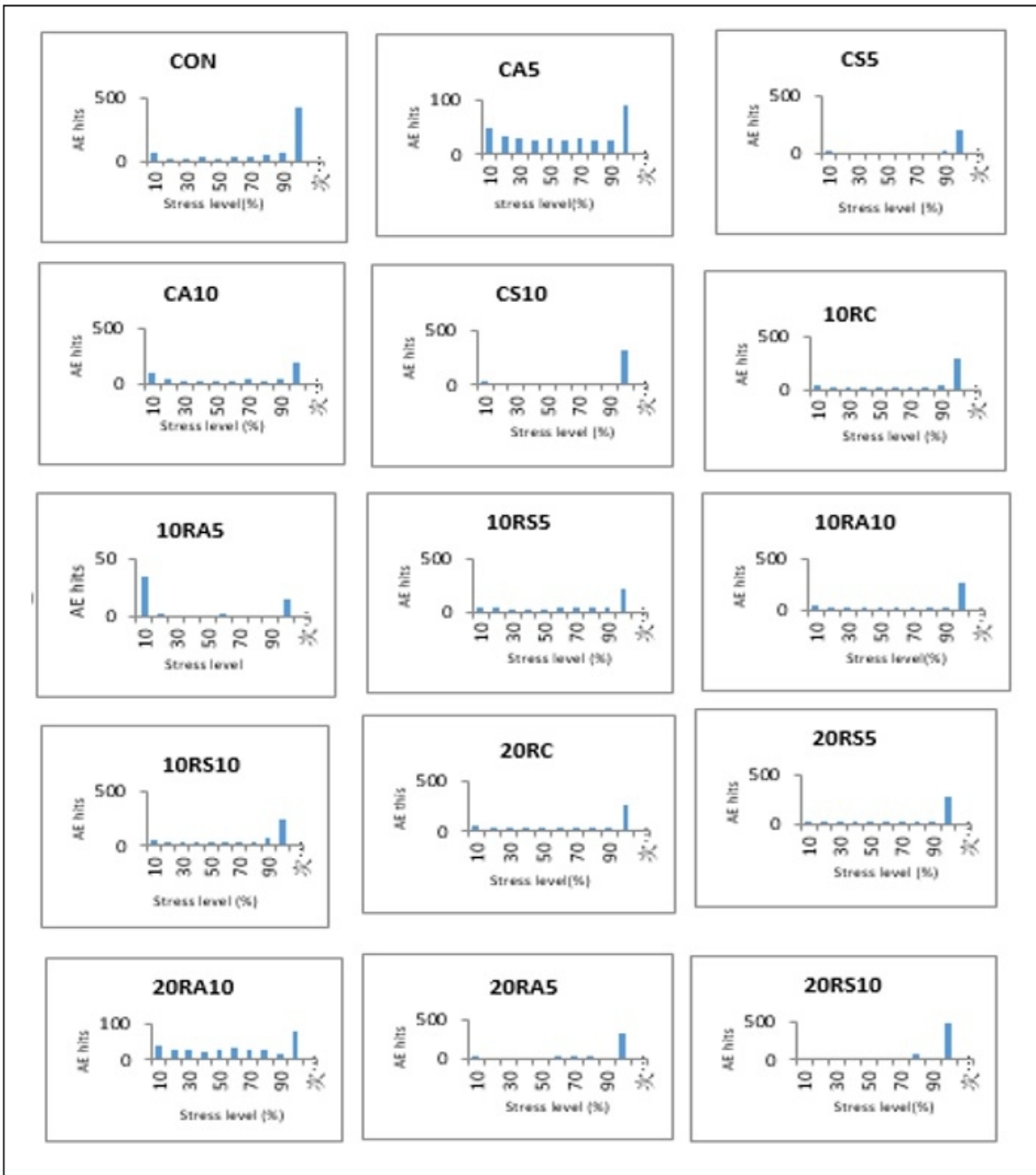


Figure 9: Relationship between AE hits and Stress Level for the Concrete Samples

5. Conclusion

- The 5% PSA without RCA slightly and 10% PSA highly decreased the workability of concrete.
- The Recycled aggregate concrete without the substituent improved the workability.
- The workability of concrete samples with the 5% SF was increased but decreased with the 10%.
- The compressive strength of concrete samples was improved with both the SF and the PSA and this is an indication of pozzolanic reaction between the cement and the binders.
- Both the 10 and 20% recycled aggregate concrete improved the compressive strength of the samples. And this is maybe because of the surface roughness of the RCA due to the previously attached mortars.
- Both the cement substituents improved the 28 and 56-day compressive strength of concrete.
- The acoustic emission activities were lower at the early stage of loading for all types of concrete samples but it was found that the cumulative hits were lower in the PSA concrete and this shows that PSA concretes were denser and had higher robustness than the other concrete samples.
- From this research, it can be concluded that both silica fume and paper sludge ash can improve the properties of concrete. although, the workability is negatively affected by the higher percentage of the substituents, so there needs to be some other researches or study on the influence of other kinds of admixture to find a solution for this drawback.
- High-quality recycled aggregate didn't have a negative influence on the properties of concrete but increased some of the properties of the concrete.

In compressive strength result, significant deviation in the result of some samples can be observed, which is due to variation of the compaction force, as several people participated in the process. This drawback can be solved while adopting another method of compaction or continuing with the same method by a single conductor.

5.1 Future Research

In this research, the workability of the samples decreased when the percentage of the PSA and silica fume increased to 10%, therefore, other types of the admixture need to be used and to be studied to overcome this drawback. Moreover, other properties such as durability properties also need to be investigated while using these kinds of the cement and aggregate substituents.

There are some kinds of by-products such as rice husk which shows pozzolanic properties when they are burnt at high temperature. These kinds of materials are also needed to be studied comprehensively.

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