REINFORCED AND PLAIN GEOPOLYMER CONCRETE SPECIMEN CROSS-SECTION COMPOSITION INFLUENCE ON CREEP STRAINS

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Abstract

Low calcium alkaline solution activated cement composite, or geopolymer concrete has been around for about 40 years. The main benefit of this material - it is partially made by utilising waste products, such as fly-ash, slags and others. It has been claimed that the manufacturing of various geopolymer binder produces up to 6 times less CO2 than the production of Portland cement. Because of the nature of the binding process of the geopolymer concrete, there are some differences in the cause of the shrinkage. Because of this aspect, the long-term property development mechanism is slightly different, and the microstructure of the specimen could be different than for ordinary Portland cement.

Although the researches regarding the geopolymer concrete composition and mechanical properties have significantly been reviewed in the previous couple of years, there has been a lack of investigations regarding the long-term properties and the conditions affecting and influencing long-term properties of the geopolymer concrete.

Two geopolymer concrete mixes are the test subject for this article - plain geopolymer and reinforced geopolymer with 1% waste steel fibers that have been subjected to creep and shrinkage tests. Waste steel fibers are the by-product of the car tire recycling process. The steel industry is not willing to take them, but if recycle these products they can be used as fiber reinforcement. The microstructure analyses with SEM were done by analysing specimens polished sections. Afterward acquired images of specimen cross-sections were analysed by determining the amount of fiber, geopolymer binder, filler, and air void amount in analysed cross-section. The results were cross-referenced with creep and shrinkage test results of analysed specimens.

The aim of this article is to determine the loading influence and geopolymer concrete microstructure influence on long-term properties by evaluating polished specimen sections.
Keywords: Geopolymer concrete, polished section micro-analysis, long-term properties

1. INTRODUCTION

In recent years there has been increased interest in low carbon footprint materials such as geopolymer concrete. Geopolymer concrete is a novel three-dimensional inorganic material that is formed due to a silicon and aluminium reaction that is activated by hydroxide silicates from sodium and potassium alkali activating solution. There are several beneficial properties such as low CO_2 emissions, low cost, low density and remarkable mechanical properties [1–4]. As the mechanical properties are similar to Portland cement concrete geopolymer concrete main advantage in this scope is its environmental contribution. If geopolymer matrix fully replaces the Portland cement the carbon emission for this material drops from 26 to 46% and reduction in costs varies from 7% less up to 39 % higher than for material with Portland cement as a binder [4, 5].

In terms of sustainable and effective resource management, it is critical to recycle and reuse industrial waste as much as possible so that the fraction of recycled material that goes to landfills is as little as possible. Furthermore, produced materials from recycled products should have new added value [6, 7]. Every year approximately 17 million tons of old tires are created, that have no further use [8]. This waste is a serious contaminant to the environment, so it is extremely important to recycle them.

Creep is an essential factor in human-made materials, especially to concrete and similar materials. Stress and deformation distribution throughout the cross-section of the specimen is affected by creep. The main creep affecting factors are the temperature of the surrounding environment, relative humidity, and applied stress level [9, 10].

As the shrinkage strains appear simultaneously to creep strains, it is crucial to measure shrinkage throughout the time of creep testing. Geopolymer shrinkage appears mainly due to water loss while curing reaction and evaporation and pore structure relevant factors, for example, alkaline activator, water content, binder material, and curing conditions. The pores develop during the polymerisation process [11].

This study shows the microstructure difference of waste steel cord reinforced and plain geopolymer concrete that has/has not been subjected to load.. And further, the microstructure composition results have been tried to link to achieved creep strains.

2. MATERIALS AND METHODS

Geopolymer cylindrical specimen matrix was based on fly ash sourced from the power plant in Skawina city (Poland). This fly ash is suitable for geopolymers because of its physical and chemical properties. The fly ash contains spherical aluminosilicate particles as well as it is rich with oxides such as SiO_2 (47.81%), Al_2O_3 (22.80%). The high value of SiO_2 and Al_2O_3 gives advantages for polymerisation [12].

Geopolymer specimens were prepared using sodium promoter, fly ash, sand (ratio sand and fly ash – 1:1). The process of activation has been made by 10M NaOH solution combined with the sodium silicate solution (at a ratio of 1:2.5). To make the composite the technical NaOH as flakes were used and water solution of sodium silicate R–145. Tap water was used instead of the distilled one. The alkaline solution was prepared by pouring the aqueous solution of sodium silicate and water over solid sodium hydroxide. The solution was mixed and leftover the night until its temperature is stabilised, and the concentrations equalised. The fly ash, sand, and alkaline solution were mixed for about 15 minutes by using a low-speed mixing machine (to receive the homogenous paste). Then half of the specimens were reinforced with 5% by mass of steel cords from recycled car tires. Then the mix was poured into the plastic moulds as it is shown in Fig.1. The specimens were hand-formed and then the air bubbles were removed by vibrating them. Moulds were heated in the laboratory dryer for 24h at 75 °C. Then, the specimens were unmolded. All the geopolymer specimen preparation was done at Cracow University of Technology (CUT), Poland.

(a) (b)

Figure 1: Plain geopolymer (a) and recycled tire steel cord reinforced geopolymer (b) concrete

All specimens were prepared according to RILEM recommendations [13]. The dimensions of the specimens were Ø 46 x 190 mm or ¼ diameter to height ratio respectfully.

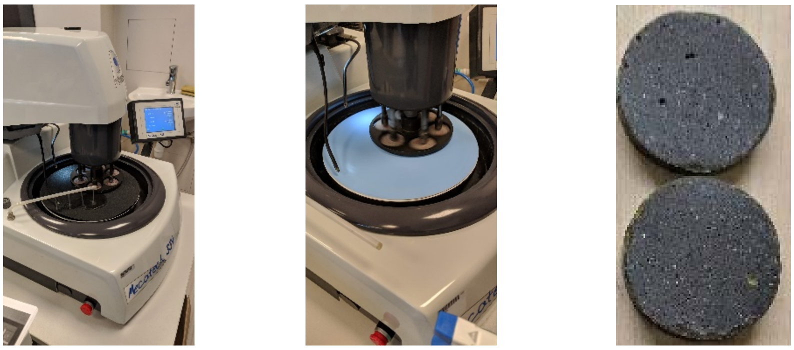
For creep deformation tests, 6 aluminium plates (10 x 15 mm) were glued to each specimen in pairs. Afterward, strain gauges were attached to those plates. For the shrinkage specimens, 1 aluminium plate was glued to the top and bottom part of the specimen. Afterward, shrinkage specimens were placed in the measuring stand to measure the shrinkage throughout testing time. All the specimen preparatory work was done at Riga Technical University (RTU), Latvia.

Creep and shrinkage strains were monitored for the first two weeks every day, afterward- every two days. During creep tests, specimens were subjected to constant load throughout the whole creep testing period. The load that specimens were subjected to was equivalent to 20% of the ultimate compressive strength, which was determined in compressive strength tests. Specimens were loaded gradually by 25% of the determined load in a short period (within 5 minutes). Creep test was carried out on tests stands shown in Fig.2.

(a) (b)

Figure 2: Specimen testing to creep strains

After creep and shrinkage tests cylinders middle parts (where the creep strain measurements were recorded) cut to disc shape specimens with a thickness of 5mm. The surfaces of specimens were saturated with polyester resin to make specimens more durable for surface polishing cycles.



(a) (b) (c)

Figure 3: Specimen polishing stages (a, b) and the result (c)

Afterward, for all specimens, their surfaces were polished by various grade sandpapers and polishing compounds. The process is shown in Fig.3. Polishing was done according to the sequences shown in Table 1.

Table 1: Specimen surface polishing steps

Polishing stage number	Polishing compound (sandpaper or paste grade) type	Polishing cycle time, minutes	Compression force to specimen polishing surface, daN
1.	P180	2	2.5
2.	P320	2	2.5
3.	P600	2	2.5
4.	P1000	2	2.5
5.	3µm	4	2.5

Afterward, specimens were delivered to Cracow University of Technology (CUT) where they were carbon plated and surface images at 25-time magnification made.

To get the optimal amount of the specimen cross-section data and images, the reviewed cross-section is divided into zones that represent the centre, middle and outside areas of the specimen. The adopted principle is shown in Fig.4.

Figure 4: Specimen cross-section division into zones

The achieved SEM images from each examined specimen's cross-section were joined together in Adobe Photoshop CC to get a full cross-section image. The next step was cross-section image dividing into layers based on what partition of cross-section (matrix, filler, air voids or reinforcement) is visible in it and RGB tone allocation. The process is shown in Fig. 5. The process step order is shown by the numbers. The layer dividing starts with the filler layer, then void layer, reinforcement fiber layer and finished with the matrix layer.

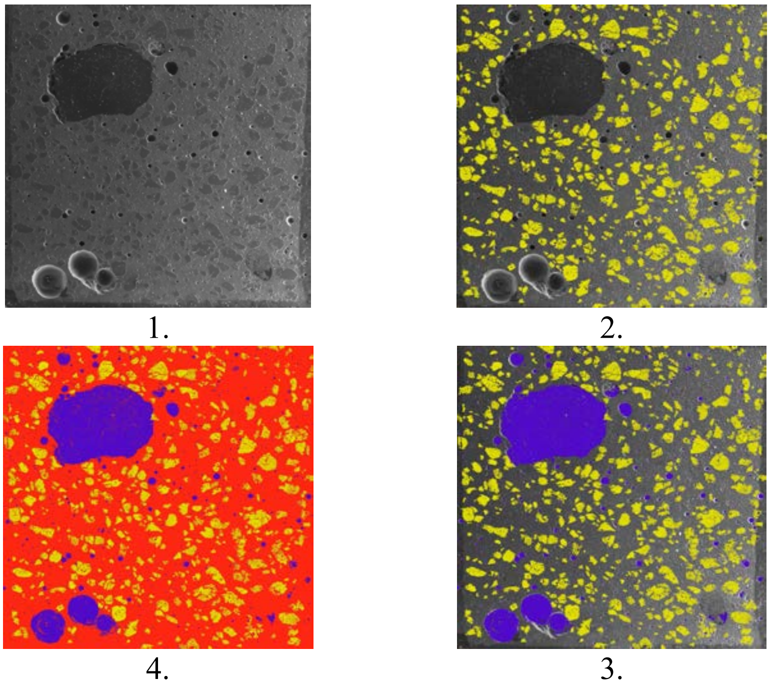


Figure 5: Image dividing sequence in layers and tone allocation

When the image was divided into layers, and the RGB tone allocated the specific tone pixel amount was divided by the number of image pixels. In doing so, the amount of particular partition of the cross-section was achieved.

3. RESULTS AND DISCUSSION

The compressive strength of the tested specimens at the beginning of the test is shown in Table 2. The specimens in the creep test were subjected to a load that was calculated from Table's 2 compressive strength values.

Table 2: Compressive strength values of 7days old cylinder specimen

Specimen material	Average compressive strength, MPa
Plain geopolymer concrete	30.37
Tire steel cord reinforced geopolymer concrete	44.52

After the initial compressive strength test, the creep and shrinkage tests were carried out for 90 days (approximately 3 months). The creep and shrinkage strain measurements are shown in Fig. 6.

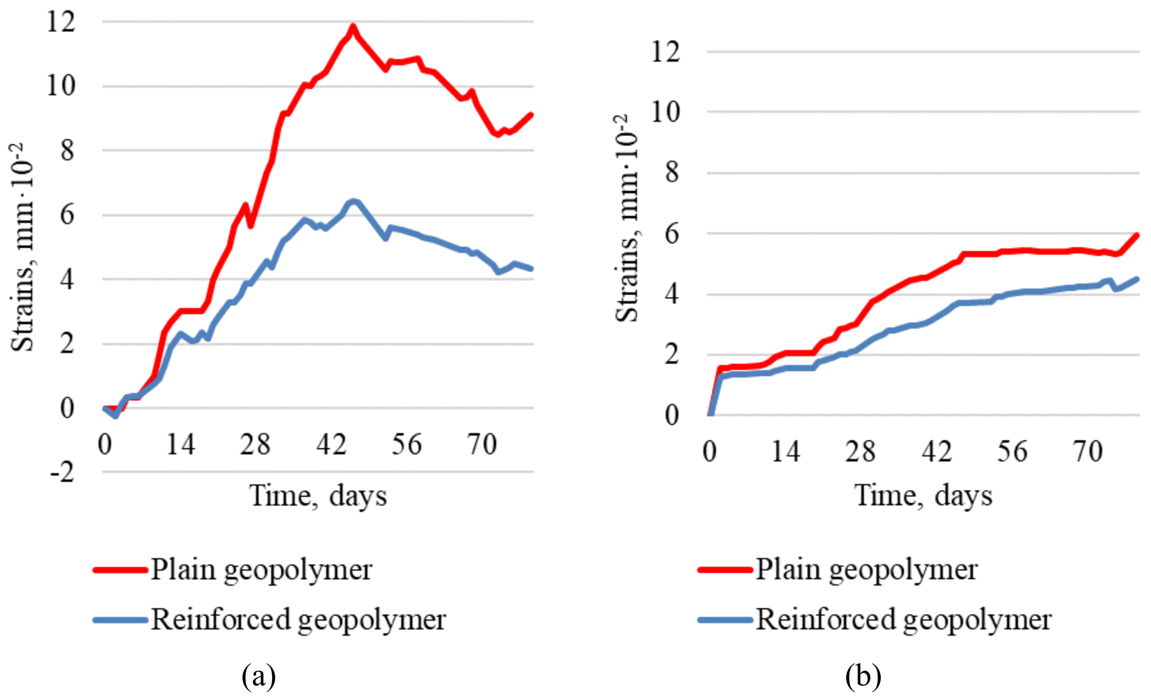


Figure 6: Shrinkage (a) and creep (b) strains

Figure 6 has shown shrinkage and creep strain curves. It is easy to determine that geopolymer concrete specimens reinforced with steel cords have significantly (~50%) less shrinkage and a bit smaller (~30%) creep properties than plain geopolymer concrete. Furthermore, it is visible that cord reinforced specimens have a slight delay in shrinkage strains to plain geopolymer specimens. That leads to thinking that steel cords from old tires have a significant restraining quality to shrinkage introduced strains.

The cross-section composition values of plain and waste steel cord reinforced geopolymer concrete is shown in Table 3.

Table 3: Average values of specimen cross-section composition

Test type	Geopolymer concrete type	Matrix amount in cross-section, %	Filler amount in cross-section, %	Air void amount in cross-section, %	Steel cord amount in cross-section, %
Shrinkage	Plain	78.96	16.91	4.13	-
	Reinforced	77.11	13.81	6.39	2.69
Creep	Plain	76.17	19.22	4.61	-
	Reinforced	77.79	15.43	5.22	1.56

From the cross-section composition values presented in Table 3, it is clear that specimens reinforced with waste tire steel cords have a significantly larger amount of air voids than plain geopolymer specimens. Also, filler distribution to creep and shrinkage specimens is uneven for both geopolymer types. For plain geopolymer, the difference is 2.31% and for reinforced specimens 1.62%. The filler amount difference in specimen cross-section composition depending on specimen type on average is 3.45% in favour of plain geopolymer. The difference is up to 2.26% for specimens that have not been subjected to load and 0.61% for those that have been loaded. This result leads to the conclusion that relatively large fiber incorporation into a geopolymer mix leads to foaming up process.

It is also apparent that the void amount for steel cord reinforced specimens that have been loaded is 19% lower than those that have not been loaded. The reason for this can be because steel cord reinforced specimens in contrast to plain ones have 32% higher compressive strength and they carried by the same amount greater load during creep tests than plain geopolymer concrete keeping the load value 20% from compressive strength load value. Therefore, the reinforcement is restraining the deformations but matrix and voids in it in this instance is the subject that is deformed for these specimens.

4. CONCLUSIONS

- The quantitative image analysis of the plain and recycled tire steel cord reinforced geopolymer concrete cross-sections shows that on average the plain geopolymer concrete specimens have from 1% up to 2.26% less amount of air voids than steel cord reinforced specimens.
- Further analysis shows that if the reviewed cross-section part is more to the centre of the specimen, then the level of the air voids decreases from 4.2% to 5.4% for plain geopolymer and from 4.7% up to 10.3% for steel cord reinforced geopolymer concrete. This could be due to insufficient vibrating to the specimens.
- Examining shrinkage and creep strain curves and cross-referencing them to achieved specimen cross-section composition, there is no direct link that cross-sections of specimens have significant flaws that would affect creep properties.
- For shrinkage strains, it is determined that for reinforced specimen greater porosity, the shrinkage strain remains lower mainly because reinforcement is restraining and delaying the strains to happen.

- Further testing and analysis are needed for specimen upper and lower parts to determine what loading influence is to specimen parts where the stress distribution is not homogeneous.

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