SUSTAINABLE USAGE OF CEMENT KILN DUST AND LIGNOSULFONATE IN DEVELOPING ASBESTOS FIBER REINFORCED ENGINEERED CEMENTITIOUS COMPOSITES

[1] Muthuraman U, [2] Hema HC, [3*] Sophia M

[1] *Department of Electrical and Electronic Engineering, Francis Xavier Engineering College, Tirunelveli, Tamilnadu 627003, India*

[2] *Department of Civil Engineering, CMR Institute of Technology, Bengaluru, Karnataka 560037, India*

[3*] *Department of Civil Engineering, CMR Institute of Technology, Bengaluru, Karnataka 560037, India*

** Corresponding author: Sophia M, sophiavarshini260492@gmail.com*

Abstract:

Engineered Cementitious Composite (ECC) is a special kind of cement mixture that has a special composition of low volume fibers and various composites to give it great ductility, high tensile strength, and the capacity to repair itself. The impact of cement kiln dust (0 to 25% weight of cement with 5% increment) on the ECC was investigated through a series of tests. Additionally, experimental research is done to see whether employing asbestos fibre to generate ECC is feasible. The current study explores the use of asbestos fibre (AF) and cement kiln dust (CKD) as potential addition and cement replacements for ECC production alternatives. In this study, fly ash is employed as a secondary cementitious material and silica sand as a fine aggregate in the creation of ECC. In this study, the characteristics of a new hybrid fiber-reinforced ECC material that contains 7.5% asbestos fibre are experimentally investigated. Also the sodium lignosulfonate (LS) is added to the developed ECC mix at various dosages (0.5, 1, and 1.5%). When 15% of the cement was replaced with cement kiln dust containing 7.5% asbestos fibre at all LS dosages, ECC performed at its best.

Keywords: ECC; asbestos fiber; cement kiln dust; lignosulfonate; mechanical behavior; fracture toughness

Introduction

Engineered cementitious composites (ECCs) are a special class of high-performance fibre reinforced cementitious composites that exhibit increased strain-hardening in tension with a minimal amount of short fibre reinforcement (Huang *et al.* 2021). An significant feature of the ECC under tensile strain is the emergence of numerous stable, minute cracks that are bridged by fibres before one of them eventually fractures (Huang and Zhang 2014). ECC has a tensile strain capacity that is hundreds of times more than that of standard concrete and demonstrates exceptional tensile strain hardening behaviour similar to that of ductile metals (Yang *et al.* 2011). Matrix characteristics and fibre bridging behaviour, which are influenced by fibre characteristics and the interfacial interaction between fibres and matrix, both have an impact on the mechanical behaviour of ECCs (Tian and Zhang 2017).

The durability of designed pulp fibre reinforced concretes with and without additional cementitious ingredients showed that the permeability qualities were enhanced by mixes of silica fume, metakaolin, and slag (Booya *et al.* 2019). The strength and durability characteristics of a hybrid cementitious composite (HCC) containing metakaolin (10%), epoxy resin (1%), and colloidal nano silica (1%), showed that the addition of synthetic fibre had a marginally negative impact on the durability characteristics while the percentages of metakaolin and colloidal nano silica showed better performance (Ramli *et al.* 2016). When compared to unreinforced material, PP fiber-reinforced alkali-activated ladle slag mortar has 150 and 7.6 times the fracture energy and toughness, respectively. The self-compacting designed cementitious composites' modulus of elasticity was enhanced, and drying shrinkage was decreased without compromising ductility. The compressive strength, elastic modulus, and energy absorption were best responded to by the 2 % PVA and 1.89 % nano-silica (Mohammed *et al.* 2017). At a 15% replacement of cement by metakaolin and a fibre fraction amount of 0.25 or 0.5 %, the performance of ECC with large volume of Metakaolin and hybrid fibres shown hopeful behaviour (El-Din *et al.* 2017). High-volume fly ash ECC performed well after being exposed to sub-elevated temperatures (6200^{0}C), while a moderate temperature treatment (6100^{0}C) improved the material's tensile characteristics (Yu *et al.* 2015). In order to boost the material's ability to absorb energy and toughness, as well as to raise its tensile and flexural strength, it is now more usual to reinforce concrete with small, randomly placed fibres for a variety of uses and applications. The Asbestos Cement Waste Sample Surface's morphological analysis revealed its comparatively high roughness and the uneven distribution of bundles of asbestos fibres with distinctly discernible primary fibres. Through the use of XRF and EDS techniques, the presence of cement- and asbestos-related oxides and elements can be seen clearly with little to no difference (Stevulova *et al.* 2020). The compressive strength decreased by 14–35% when cement was replaced with 5–20% asbestos-free fibre cement, although this was still acceptable for structural purposes. Numerous buildings still have roofs made of asbestos cement materials, despite the fact that the manufacturing of asbestos fibres has been outlawed in some regions of the world due to its potential to cause cancer. According to Kusiorowski *et al.* (2016), ACW (Asbestos Cement Waste) exhibits chemical-mineralogical properties that are advantageous to the building sector. In this regard, ACW served as a raw material for the manufacture of calcium sulfoaluminate clinker and Portland clinker (Yvon and Sharrock, 2011) and the powders used had good pozzolanic activity which further shown that they could be recycled as a mineral additive in the production of building products (Colangelo et al. 2011). The inert bulk material's granulometric, microstructural, and mineralogical properties point to the possibility of successfully reusing asbestos-containing wastes as a secondary raw material in the ceramics industry (Marian *et al*. 2021).

Background of the study

Alternate materials are a tried-and-true method of improving concrete's performance. The usage of cement kiln dust in ECC has been successfully used to improve performance, but little is known about it. Few research have examined how well ECC performs when CKD is used, and as of this writing, none have attempted to produce fibre reinforced ECC by substituting cement kiln dust for cement and LS dose. Through some tests, this research aims to demonstrate how the CKD well behaved in combination with the LS dose might enhance the qualities of asbestos fibre reinforced ECC.

Research Significance

Despite the studies done on the use of cement kiln dust as an additional cementitious material in concrete/composites, its impact on the strength parameters and fracture behaviour of asbestos fibre reinforced concrete has not been well investigated. Additionally, no research has been done to examine the effects of lignosulfonate combined with asbestos fibres on various parameters of concrete/cement composites. As a result, a thorough analysis of the impact of cement kiln dust on ECC performance as well as the contribution of lignosulfonate to the ECC has been done in this work.

Experimental Investigation

Materials and mix proportions

In this investigation, Ordinary Portland Cement (OPC) of grade 53 conforming to IS 12269-1987 was used in all mixtures. class F fly ash (FA) were utilized as binder, and silica sand was added as fine aggregate. CKD was collected from the Indian Cements Plant, Tamilnadu, which is used as a cement replacement material. The cement-CKD blended pastes were prepared using a w/b ratio of 0.3 and the CKD was used as cement replacement in varying proportions of 5, 10, 15, 20 and 25% by weight of cement. The chemical compositions of cement, cement kiln dust and fly ash, as determined by XRF analysis, are shown in Table 1. The asbestos fiber obtained from Astraa chemicals, Tamilnadu is employed at constant percentage level of 7.5% in the present research work. In order to keep the combination workable and achieve uniform fibre dispersion, lignosulfonate was used in the mixture at various dosages (0.5%, 1%, 1.5%).

A mixer with a half-bag capacity was used to combine ECC and regular concrete. Powdered components including cement, sand, and fly ash were added first and mixed for three to five minutes to make the ECC mixtures. After fully blending the super plasticizer and lignosulfonate with water, the dry mix received the same addition and was again mixed for 5 minutes. Later, fibres were gradually added to the cement mortar paste and blended until equally distributed. Fibers were carefully introduced and slowly incorporated throughout the mass to prevent balling in the ECC mix. The mixing time was increased after the fibre was introduced, but not by more than 7 minutes, to reduce the effect of thixotropy (Felekoglu *et al.* 2009). The ECC mixtures were then inserted into the appropriate moulds in the following step. No external compaction was necessary because of the material's great workability and self-consolidation. Table 2 presents the mix details for developed ECC.

Testing Methods adopted

According to IS: 1199 - 1959 (2004), the workability of fresh concrete can be assessed using a mini slump cone test. After 28 days of curing, cube specimens of the standard dimension 150 mm x 150 mm x 150 mm underwent the compressive strength test in accordance with IS: 516-1969 (2004). On a coupon specimen measuring 330 mm x 60 mm x 30 mm, a direct tensile strength test was conducted. After 28 days of curing, the modulus of rupture can be calculated using hardened concrete prisms of standard size 100 mm x 100 mm x 500 mm in accordance with IS: 516-1959 (2004). Utilizing the compressometer method, the elasticity modulus of concrete was determined. A cylindrical specimen with a 100 mm diameter and 300 mm height was used for this test, and a compressometer was attached to it. A three-point bending test configuration was used to determine the matrix fracture toughness in line with ASTM E399-20a. Despite the fact that ASTM E399-20a is a standard for measuring the fracture toughness of metals, it may also be used to assess the fracture toughness of brittle materials that exhibit small-scale yielding, proving the validity of the assumptions made by linear elastic fracture mechanics.

Results and Discussion

Fresh state characteristics

When the fly ash included in ECC and CKD were added to the mix, a workability test was performed to determine the resistivity in the flow because when they were added, they will absorb a significant amount of water, which in turn will limit the workability. Therefore, it is required to manufacture ECC mixes with higher workability in order to make mixes that are simple to install, compact to handle, and transport, as well as to obtain higher strength with higher durability performance. For all ECC mixtures, the water to cement ratio was consistently maintained at 0.3. The workability qualities of ECC mix were assessed, and an experimental examination using a micro slump cone test was conducted. The outcomes are depicted in Figure 1. The presence of asbestos fibres may decrease flow, although ECC mixes with fly ash and CKD replacement compensated for the loss of workability and managed to improve flowability by adding sodium lignosulfonate dosages. The slump value, which falls between 67 and 80 mm, is found to be suitable for creating a matrix that can be used. It is abundantly clear from the data that LS was added to the ECC matrix to enhance the flowability of the created mixes.

Strength characteristics

Compressive strength

The overall finding is that the mix's density rises as the amount of AF and binder components like CKD and fly ash increases. Although fly ash slows down the hydration process in concrete, it reacts with the free lime in the cement matrix to create more cementitious material, which boosts the material's long-term strength. The delayed strength enhancement brought on by the fly ash concentration was partially offset by the addition of CKD to the ECC matrix. By raising the CKD substitution level and the fly ash content in the ECC, the density of the ECC is improved. The compressive strength increases when CKD content is up to 15% of the cement weight, after which it tends to decline, as shown in Figure 2. It happens because adding more CKD to ECC than is necessary causes the mixture to become unworkable, which lowers its strength. At different dose levels, the inclusion of LS in the ECC matrix also assisted in improving their compressive strength. At 1.5% LS dose including 7.5% asbestos fibre, the 15% CKD replacement's ideal strength was obtained. Beyond 15% CKD replacement, the improved compressive strength starts to deteriorate. This is mostly because secondary hydration products formed, delaying the early strength of the ECC specimens. At different LS dosages, the highest strength increment of approximately 13.43%, 19.98%, and 24.20% is achieved for the CK15L0.5, CK15L1, and CK15L1.5 mixtures. With a substitution of 5%, 10%, 15%, 20%, and 25% for CKD, the greater dosage of LS produced better strength percentages of about 13.25%, 19.65%, 24.20%, 22.25%, and 20.54%. Although CKD and LS together improved the compressive performance of ECC, their combined action did not have an influence at higher replacement levels because early strength attainment was delayed. While the addition of CKD with ECC containing fly ash might speed the hydration process initially, it slowed it down mostly during the quiescent and acceleration phases. The pozzolanic reaction's consumption of $Ca(OH)_2$ led to better mechanical characteristics being attained. the process of continuously filling the prepared fractures with hydration agents to mend cracks. When pozzolanic elements like fly ash and CKD are utilized in the manufacturing of ECC with Portland cement, this sort of self-healing is the predominant process. Additionally, it is mentioned that the carbonation mechanism filled the preexisting fissures with calcium carbonates as calcium hydroxide created during Portland cement's hydration reactions reacted with atmospheric CO_2.

Direct Tensile strength

Direct tensile strength was conducted on an ECC mix with asbestos fiber containing varying volume proportion of CKD such as 5%, 10%, 15%, 20% and 25% along with various proportion of LS added at 0.5%, 1% and 1.5% dosages in ECC. The test result obtained by applying direct tensile load on a coupon specimen is shown in Figure 3. The direct tensile strength improved upto 15% of CKD substitution as cement replacement in the ECC matrix. It is also observed that as the LS dosage increased the direct tensile strength gets improved and 1.5%LS found to be optimum. The asbestos fiber actively dispersed in the ECC matrix which helped in effective formation of dense matrix along with combined action of CKD and fly ash. The optimum tensile strength of about 5.57 MPa is attained for CK15L1.5 mix followed by 4.98 MPa for CK15L1 and 4.35 MPa for CK15L0.5 at 1.5, 1 and 0.5% respectively.

Modulus of Rupture measurements

The prismatic samples were put under flexural load to determine the ECC specimen's rupture modulus, and the findings are shown in Figure 4. CKD content is shown to increase with increase in modulus of rupture up to 15%, after which it tends to decrease, but within the range of control mix (CTRL). This is because the inclusion of AF and CKD increases the flexural strength of ECC that contains fly ash. By evenly spreading among them, the asbestos fibre contained in the ECC matrix contributes to the formation of a matrix that is well bound. The strength values for the created ECC mixes ranged from 6.1 MPa to 8.41 MPa, whereas the value for the control mix was 4.98 MPa. The mixtures showed an improved percentage of around 42.6%, 61.7%, and 68.9% at 0.5, 1, and 1.5% LS dosage, respectively, at 15% CKD substitution. Following 1% and 0.5% LS dosages, the ECC's maximum potency was attained at 1.5% LS dosage. The enhanced content of CKD, which was thoroughly mixed with the fly ash component in ECC, is mostly to blame for the better performance.

Modulus of Elasticity measurements

After 28 days of water curing, a modulus of elasticity test was performed on a cylinder specimen produced of ECC with varying percentages of CKD, LS, and constant asbestos fibre content. The findings are shown in Figure 5. The modulus of elasticity increases with the addition of CKD up to 15% to the weight of cement for all LS doses in ECC, after which it begins to decrease. All ECC mixes have elasticity moduli that are higher than cement mortar mix. The elastic modulus values for the generated ECC specimens, which range from 19.3 MPa to 25.3 MPa, are satisfactory. The effective dispersion of asbestos fibre, together with the fine-grained CKD and fly ash, is primarily responsible for the increased value. The fly ash content in the ECC and the replacement CKD bonded well and created a dense matrix structure. Additionally, it was found that increasing the LS dosage from 0.5% to 1.5% produced superior results, which was consistent with the created ECC specimens' compressive strength. For ECC mixes comprising 15% of CKD substitution, the improved percentage of elastic modulus was about 21.04% at 0.5%LS, 23.11% at 1%LS, and 30.35% at 1.5%LS doses. When comparing the ECC specimen findings at different LS dosages, the largest dosage used, roughly 1.5%, produced a higher elastic modulus value.

Fracture Toughness measurements

The ability of a material to resist brittle fracture in the presence of a crack is expressed quantitatively as fracture toughness. The variation of matrix fracture toughness test results on developed ECC specimens (with and without AF) is demonstrated in Figure 6. At each level of the CKD/LS substitution, the matrix fracture toughness increases as their content increases. CKD can be viewed as inert fillers in the developed ECC combinations that this study looked at. Together, fly ash and CKD maintain the composite matrix's density, which greatly improved the fracture toughness. The matrix fracture toughness has improved due to the effective filling behavior of finer CKD and fly ash particles which also promotes the self-healing behavior due to tighter crack width. The fracture toughness ranges between 0.33 to 0.51 $MPam^{1/2}$ in which the higher improvement is evident when the LS dosage reaches 1.5%. At this dosage, the CK25L1.5 mix exhibited greater toughness of about 0.51 $MPam^{1/}2$ when compared with all the other developed mixes. Since the mixes showed higher fracture toughness on increasing substitution of both CKD and LS, the 25% CKD mixes at various LS dosages proves to be less prone to brittle fracture. The finer grain size of CKD and fly ash helped in developing a ECC matrix without causing a significant loss in strength.

Conclusions

Fly ash's high pozzolanic reactive nature and the addition of asbestos fibre often resulted in a decline in the workability of ECC, which may have been the primary cause. However, this impact was effectively counteracted by the addition of sodium LS, which aids in the development of an ECC with improved workability, with a range of 68–81 mm. The secondary hydration products created by the presence of fly ash and CKD in the ECC matrix filled the prepared cracks thanks to the crack healing and carbonation mechanism. Although CKD and LS together enhanced ECC performance, their combined action had no effect at higher replacement levels because early strength attainment was postponed. As a result, 15% CKD was found to be the ideal replacement level. The increased direct tensile strength, elastic modulus, and modulus of rupture are mostly attributable to the active dispersion of asbestos fibre in the ECC matrix, which aided in the efficient creation of a dense matrix when paired with the actions of CKD and fly ash. The addition of CKD and fly ash present in the matrix improves ECC's ability to achieve good strength, better performance, and produce the right formation of C-S-H. When CKD is substituted for cement and LS additions are added to ECC, the resultant composites' fracture toughness increases due to an increase in tensile ductility and a decrease in crack width. The matrix fracture toughness has enhanced as a result of the effective filling behavior of finer CKD and fly ash particles, which also promotes the self-healing behavior due to tighter crack width. The generated ECC mixes are also seen to fall within the following ranges for the 28-day tests on compressive strength, direct tensile strength, modulus of rupture, elastic modulus, and fracture toughness: 33.89-42.09 MPa, 2.94-5.57 MPa, 4.98-8.41 MPa, 19.34-25.21 MPa, and 0.33-0.51 Mpa respectively.

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None

Conflict of Interest

The authors declare no conflict of interest.

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Table 1. Chemical composition of raw materials employed

Ingredients	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3
Cement	21.02	4.99	4.08	63.01	0.89	0.23	0.51	2.92
Flyash	51.7	23.9	5.22	7.65	0.9	1.4	0.58	0.91
CKD	15.8	3.6	2.8	63.8	1.9	3	0.3	1.7

Table 2. Mix proportion details of developed ECC mixes

Mix Id	Cement (%)	CKD (%)	Fly Ash (%)	Sand (%)	AF (%)	LS (%)
CTRL	100	-	120	100	-	-
CK5L0.5	90	5	120	100	7.5	0.5
CK10L0.5	85	10	120	100	7.5	0.5
CK15L0.5	80	15	120	100	7.5	0.5
CK20L0.5	75	20	120	100	7.5	0.5
CK25L0.5	70	25	120	100	7.5	0.5
CK5L1	85	5	120	100	7.5	1
CK10L1	80	10	120	100	7.5	1
CK15L1	75	15	120	100	7.5	1
CK20L1	70	20	120	100	7.5	1
CK25L1	65	25	120	100	7.5	1
CK5L1.5	80	5	120	100	7.5	1.5
CK10L1.5	75	10	120	100	7.5	1.5
CK15L1.5	70	15	120	100	7.5	1.5
CK20L1.5	65	20	120	100	7.5	1.5
CK25L1.5	60	25	120	100	7.5	1.5

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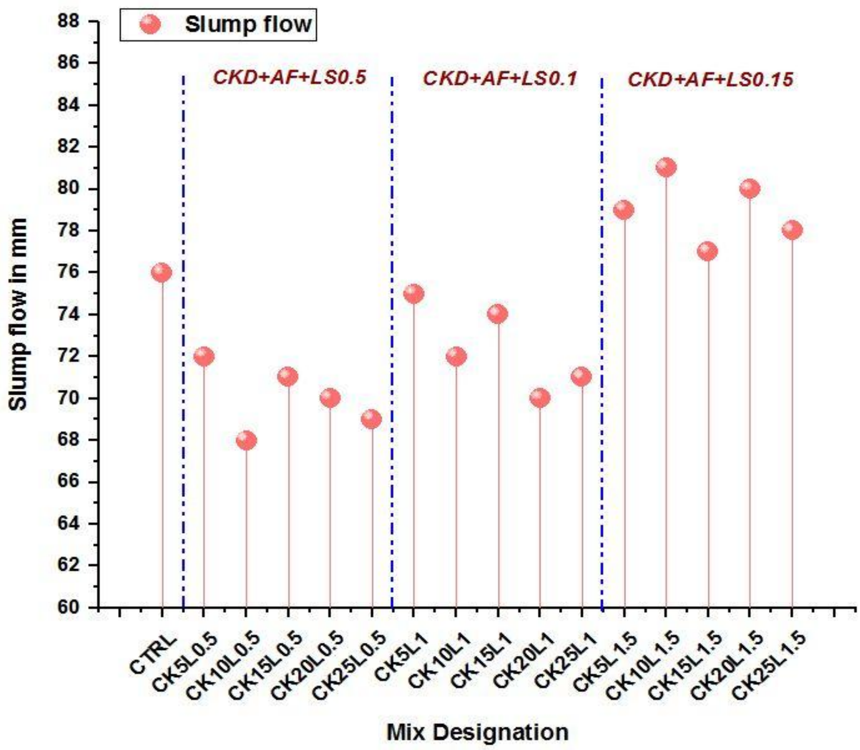

Fig. 2. Strength behavior of developed ECC mixes.

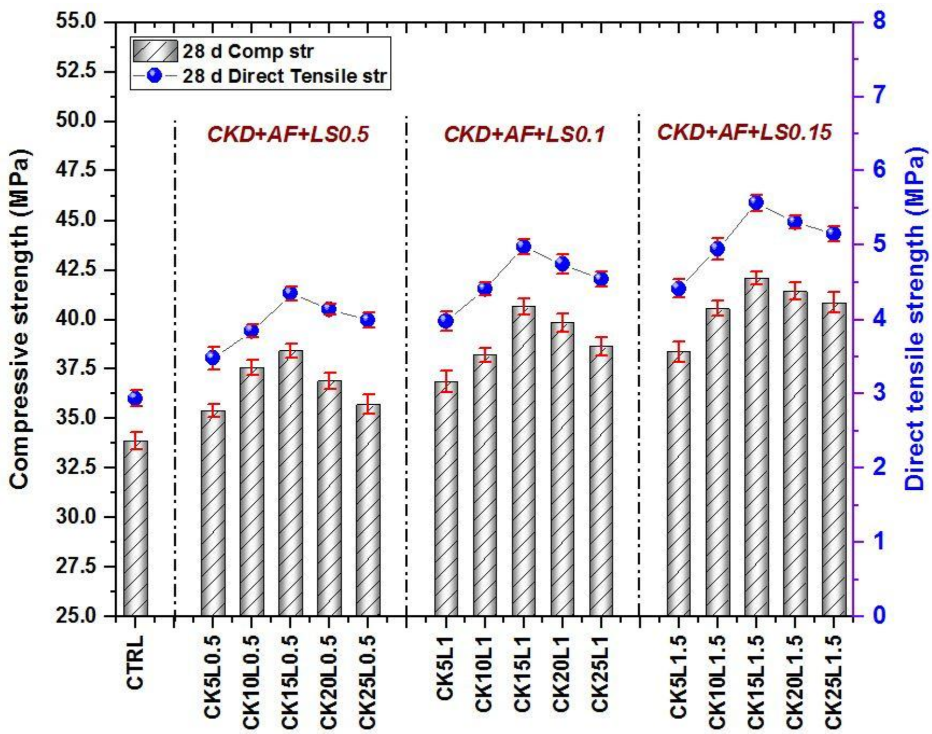

Fig. 3. Modulus of Elasticity and Rupture of developed ECC mixes

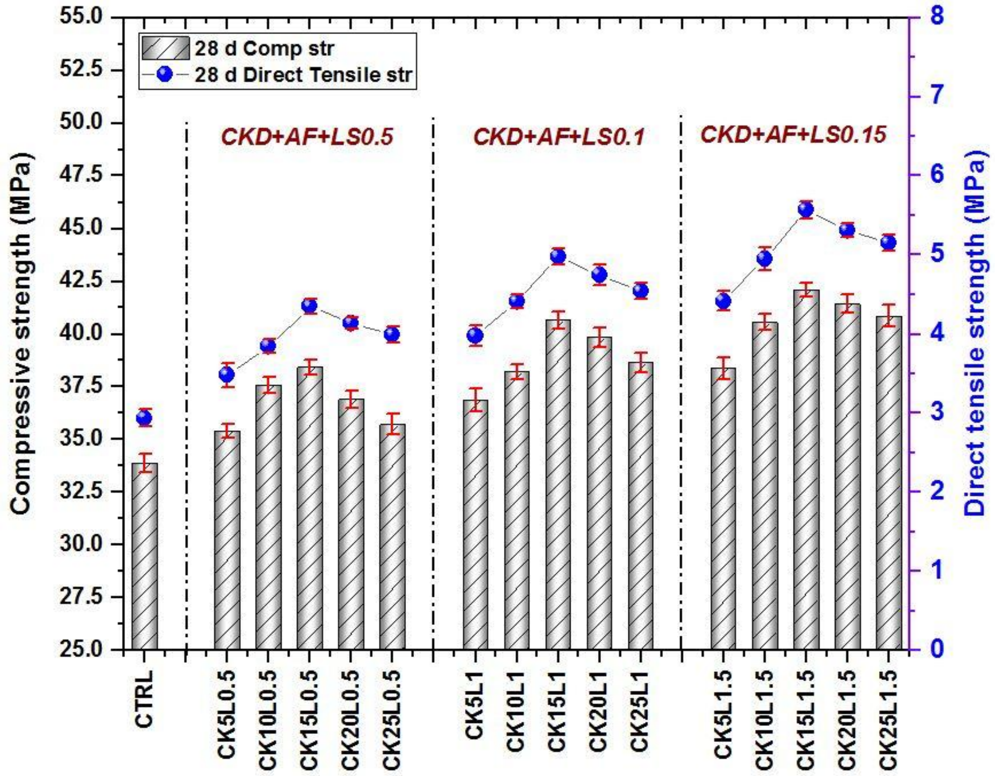

Fig. 4. Fracture toughness of developed ECC mixes