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EFFECT OF USING CATHODE-RAY TUBES (CRT) WASTE GLASS ON CONCRETE PROPERTIES

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EFFECT OF USING CATHODE-RAY TUBES (CRT) WASTE GLASS ON CONCRETE PROPERTIES

Abstract

Cathode-ray tube (CRT) glass is a hazardous material that should be responsibly managed when disposed. One of the possible options for recycling CRT waste glass is using it as fine aggregates in concrete for its richness in silica. For the aim of evaluating concrete with this material, four mixes with replacement levels of 0%, 10%, 20% and 30% are prepared. Workability, hardened density, ultra-pulse velocity, compressive strength, tensile strength, and static modulus of elasticity were examined. Experimental results showed that the use of CRT improved properties of concrete at certain replacement levels. CRT glass improved the workability of concrete where mixes with CRT required less water reducer to reach the same slump. Hardened density increased with the increase of the CRT glass. The mechanical properties of the concrete were enhanced at 10% replacement level only. In general, CRT glass proved to be adequate as a replacement for sand in concrete

Keywords

CRT, concrete, waste glass, compressive strength

1. INTRODUCTION

Large amounts of waste glass is generated each year due to its wide range of applications (Zheng, 2013). While it is a highly recyclable material, glass is non-biodegradable (Deshmukh et al., 2019). Cathode-ray tubes (CRTs) are made of 85% glass (Andreola et al., 2005, 2007). It is expected that massive quantities of CRTs will be discarded in the coming decades (Poon, 2008). However, the burying of CRTs in landfills causes environmental concerns (Seeberger et al., 2016), as they contain lead and other heavy metals (Singh et al., 2016). Hence, suitable recycling of CRT glass must be carried out to prevent such problems. One of the fields to reuse CRT waste glass is construction materials, since it is impermeable and rich in silica which makes it suitable for replacing sand (Yao et al., 2018).

In Fact, it is not uncommon to replace sand by waste materials in concrete. Waste plastic straw, for instance, was proved to increase tensile strength of concrete (A. Jahami et al., 2020; Khatib et al., 2020) and improve the ductility of reinforced concrete (A. H. Jahami et al., 2019). Plastic waste caps efficiently reduced the density of concrete but compromised ductility (A. Jahami et al., 2019; Khatib et al., 2019). Waste glass, when used as a replacement to sand in concrete, was observed to decrease consistency yet enhance modulus of elasticity (Dhir et al., 2018). Recycled glass improved mechanical properties of concrete and resistance to chloride ion penetration (Du et al., 2014).

CRT waste glass, on the other hand, was observed to have a positive effect on the workability of concrete and mortar. Hui et al. (Hui et al., 2011) found an increase in slump flow in addition to decrease in flow loss rate when using CRT waste glass. Ling et al. (Ling et al., 2011) noticed a gradual improvement of flow with higher replacement level of CRT waste glass. Zhao et al. (Zhao et al., 2013b) reported similar results including less bleeding and segregation in mixes containing higher replacement level of CRT waste glass. Impermeable nature and smooth surface of CRT waste glass are considered the reason behind this improvement in workability (Kou et al., 2009).

Studies on the influence of CRT waste glass on the compressive strength of concrete held different results. Zhao et al. (Zhao et al., 2013a) noticed an increase in compressive strength when using CRT waste glass. Similar results were found by Walczak et al. (Walczak et al., 2015), where CRT waste glass has a positive effect on strength. However, many other studies reported contradicting results. Ling et al. (Ling et al., 2011) found that CRT waste glass decreases compressive strength of mortar. Liu et al. (Liu et al., 2018) and Wang et al. (Wang et al., 2019) also noticed a reduction of compressive strength when replacing sand by CRT waste glass in the mix.

There are limited studies that focus on mechanical properties of concrete containing low replacement levels of CRT glass that could hold different trends than those in literature. Thus, four concrete mixes are prepared through replacing sand by CRT waste glass levels with substitution levels of 0%, 10%, 20% and 30%. Workability is assessed through slump test. Hardened density and ultra-pulse velocity are tested. Also, compressive strength, splitting tensile strength, and static modulus of elasticity are examined.

2. EXPERIMENTAL PROGRAM

2.1. Materials

ASTM Type I Ordinary Portland cement (OPC) was used in this study. Natural sand having particle size less than 4.75 mm and natural gravel having particle size between 5 mm and 19 mm were used as fine aggregates and coarse aggregates, respectively. Six colored waste CRT televisions were brought from local electronics store, disassembled, and then the CRT was crushed so that the maximum particle size did not exceed 4.75 mm (Figure 1). In addition, high range water reducer was used in all mixes. Figure 2 shows the particle size distribution of sand and crushed CRT glass.

Fig.1: Crushed CRT glass

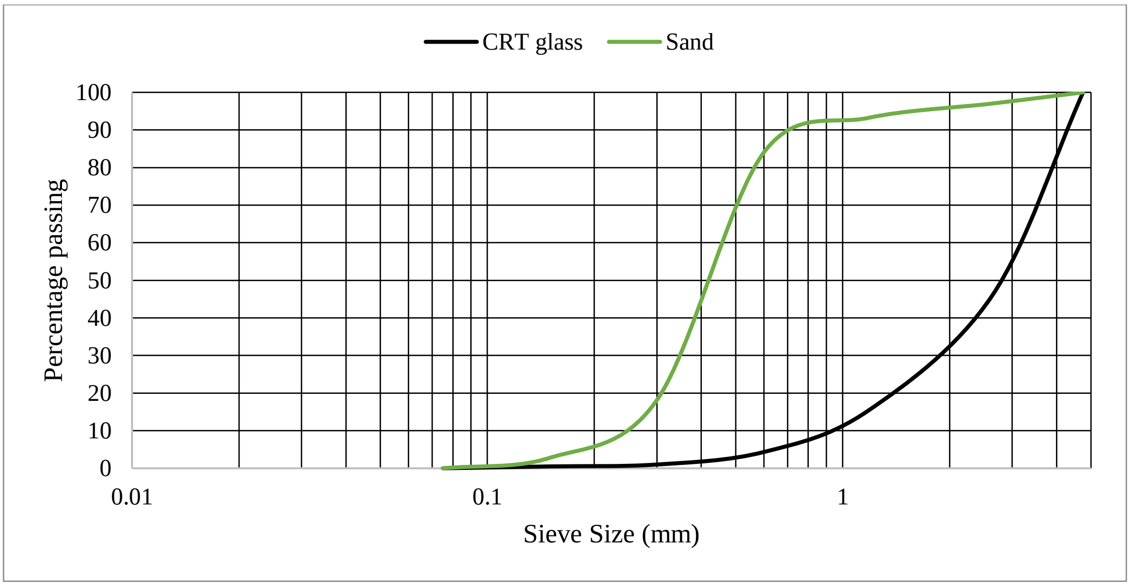

Fig.2: Particle size distribution of CRT glass and sand

2.2. Mix Proportions and Preparation

Four concrete mixes are prepared; one control and three mixes where sand is replaced by crushed CRT glass with replacement levels of 10%, 20% and 30% by volume. All mixes had a constant water-cement (W/C) ratio of 0.52 and proportions of 1:2:4 (cement: sand : gravel). Superplasticizer (SP) was used with different proportions ranging from 0.7% to 1.6% of the mass of OPC. Table 1 shows the mix proportions of concrete.

Table 1: Mix proportions

Mix notation	Material compositions (Kg/m^3)						
	OPC	Sand	CRT	Gravel	Water	SP	W/C
CRT0	334	668	0	1336	173.68	5.34	0.52
CRT10	334	601	74.5	1336	173.68	4.34	0.52
CRT20	334	534	150	1336	173.68	3.34	0.52
CRT30	334	468	224	1336	173.68	2.34	0.52

A pan mixer was used to prepare the concrete mixes. First, cement was mixed with fine aggregates and coarse aggregates for 3 minutes. Second, half of the amount of water was added and components were mixed for further 3 minutes. After that, the remaining amount of water was added including SP and concrete was mixed for 2 minutes (Figure 3).

Fig.3: Concrete after mixing in the pan mixer

Following the end of mixing, slump test was conducted. Then, concrete was poured into steel and plastic molds. For each mix, 12 steel cubic molds of size 100*100*100mm and 3 cylindrical plastic molds of size 300*150mm were used.

2.3. Test Methods

Slump of fresh concrete was determined based on procedures by BS EN 12350-2 (EN, 2009a). The hardened density of concrete was obtained in accordance to BS EN 12350-6 (EN, 2009b). Ultrasonic pulse velocity (UPV) at ages of 1,7,28,90 days was determined by BS EN 12504-4 (EN, 2004) and using Equation (1). The setup is shown in figure 4.

$$UPV = L/T \qquad \text{Eq. (1)}$$

Where (UPV) is the velocity in meters/second, (T) is time in seconds measured using a specialized machine, and (L) is length of cube in meters.

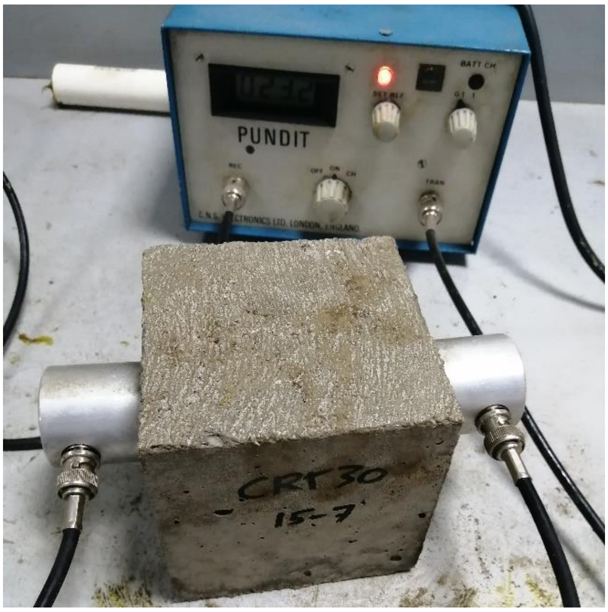

Fig.4: The setup of UPV measuring

The compressive strength test was performed by BS EN 12390-3 (EN, 2002) on 100×100×100 mm concrete cube specimens at ages 1,7,28,90 days. The value is the average of 3 specimens. Also, splitting tensile strength of 150×300 mm cylinders was measured at 28 days by BS EN 12390-6 (EN, 2009c). Equation (2) is used to calculate the splitting tensile strength.

$$F_T = 2P/\pi.D.L \qquad \text{Eq. (2)}$$

Where (FT) is tensile strength in MPa, (P) is the maximum applied load in newtons, (D) and (L) are the diameter and length of the cylinder in millimeters, respectively. Splitting tensile test setup is shown in figure 5.

Fig.5: The setup of tensile splitting strength testing

The static modulus of elasticity is measured at 28 days conforming to BS EN 12390-13 (EN, 2013). The reported value is the average of 3 specimens.

3. RESULTS AND DISCUSSION

3.1. Workability

All four mixes maintained an approximately matching slump of 178 ± 2 mm. However, quantity of SP used in each mix is different. Figure 6 shows the percentage of SP by weight of cement used in each concrete specimen. For CRT0 mix, the SP used is 1.6% of weight of cement. This amount decreased gradually to reach 0.7% for CRT30 mix. As it is evident, as replacement level of CRT glass increases, the SP percentage needed to maintain approximately the same slump decreases. Since W/C ratio is fixed, this indicates a better workability when using CRT glass. This is consistent with previous studies (Kim et al., 2018; Liu et al., 2020; Ouldkhaoua et al., 2020; Zhao et al., 2013b).

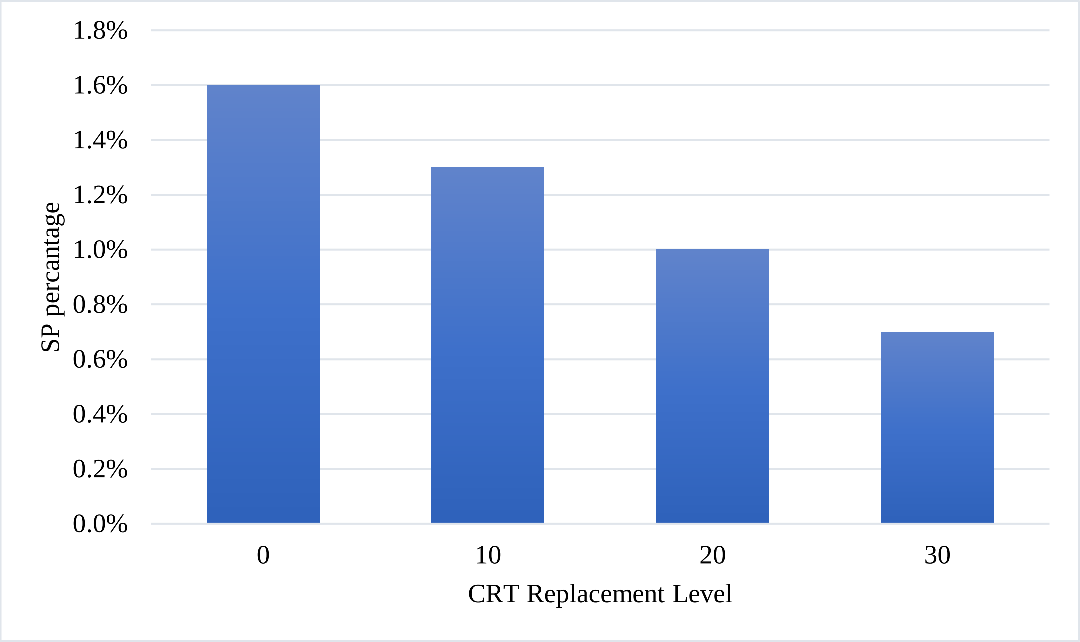

Fig.6: SP percentage used in each concrete mix

3.2. Hardened Density

Figure 7 shows the density of each CRT concrete samples. Density increased from 2465 kg/m^3 at 0% replacement level to 2534 kg/m^3 at 30% replacement level. This increase is plausible since the specific gravity of CRT glass generally exceeds the specific gravity of natural sand. It is observed however that this increase is not gradual, rather exponential, and could be described in the following equation:

$$D = 2463 + 1.78e^{0.122R} \qquad \text{Eq. (3)}$$

Where (D) is the density of concrete in Kg/m^3 and (R) is the replacement level in %. Note that this equation is only viable for replacement levels between 0% and 30%.

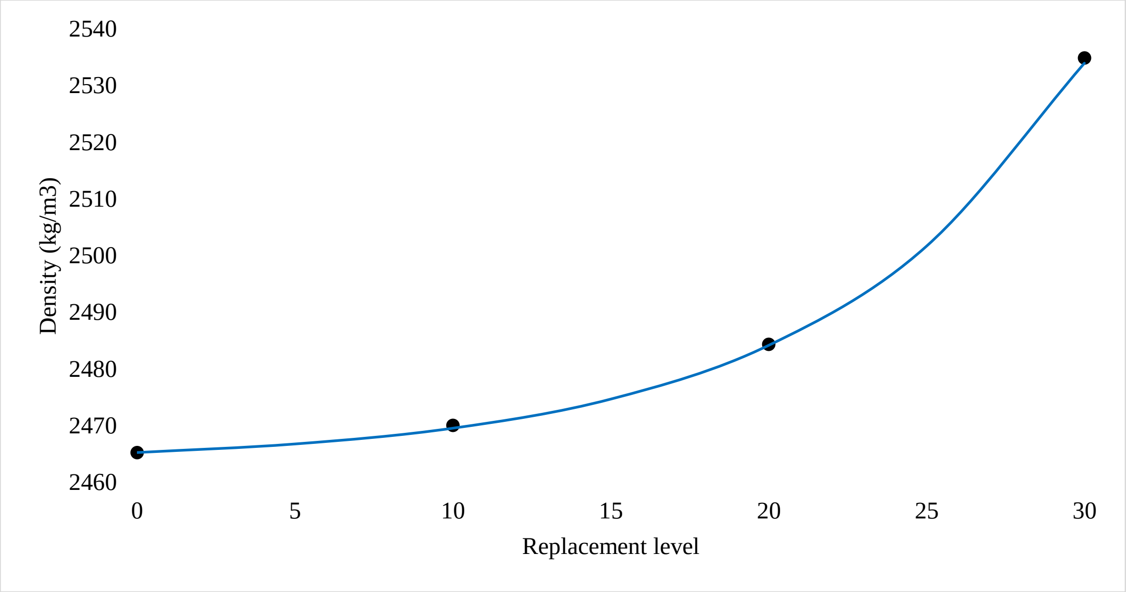

Fig.7: Density of concrete samples at different replacement levels

3.3. Compressive Strength

The 1,7,28,90 days compressive strength of the concrete mixes are shown in Fig 8. The results show an increase in strength at 10% replacement level then a decrease beyond that. For example, at 28 days, compressive strength of concrete mixes increases from 31.4 MPa for control mix to 37.9 MPa at 10% replacement level then decreased to 35.9 MPa and 34.4 MPa at 20% and 30 % replacement levels, respectively. Despite of the decrease beyond 10% replacement levels, the compressive strength remains higher than the control mix. This is consistent for all curing ages. A study that replaced sand by CRT glass at 0,5,10,15,20% replacement levels found similar results at day 7 where compressive strength increased at 10% replacement level then decreased at 20% (Yildirim, 2018).

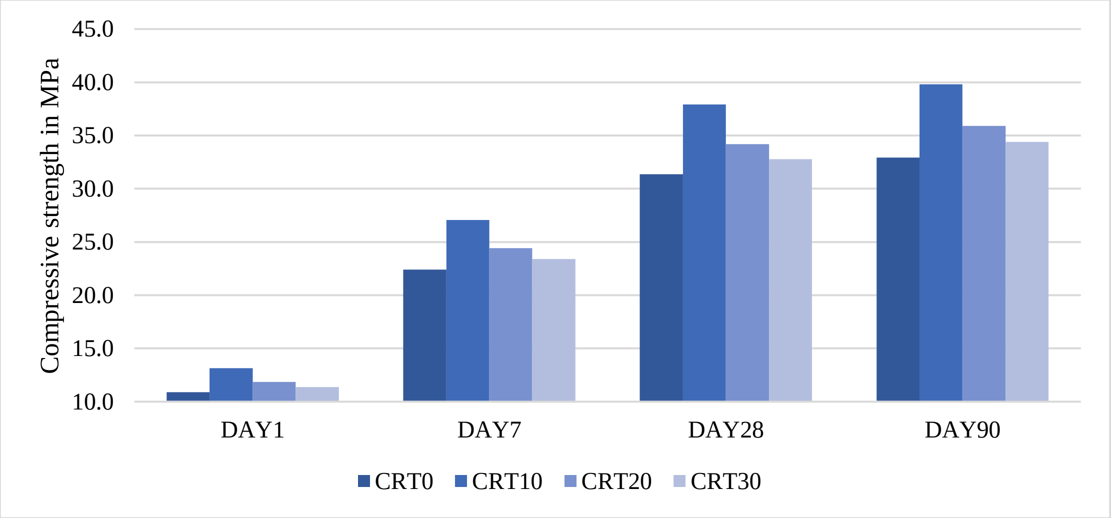

Fig.8: Compressive strength of concrete specimens at different replacement levels and curing ages

Ranges of minimum and maximum compressive strengths for all specimens were 10.9–13.2, 22.4–27.1, 31.4–37.9, and 32.9–39.8 MPa for 1, 7, 28, and 90 days, respectively. It is worthy to mention that highest increase was at 90 days, where the pozzolanic activity of the CRT glass could be the reason behind this trend (Lee et al., 2013).

3.4. Splitting Tensile Strength

Figure 9 shows the splitting tensile strength of concrete samples at 28 days. Despite the slight difference, the trend is similar to that of compressive strength, where the tensile strength increases from 2.95 MPa at 0% replacement level to 3.26 MPa at 10% replacement level then decreases to 2.96 MPa and 2.92 MPa at 20% and 30% replacement levels, respectively.

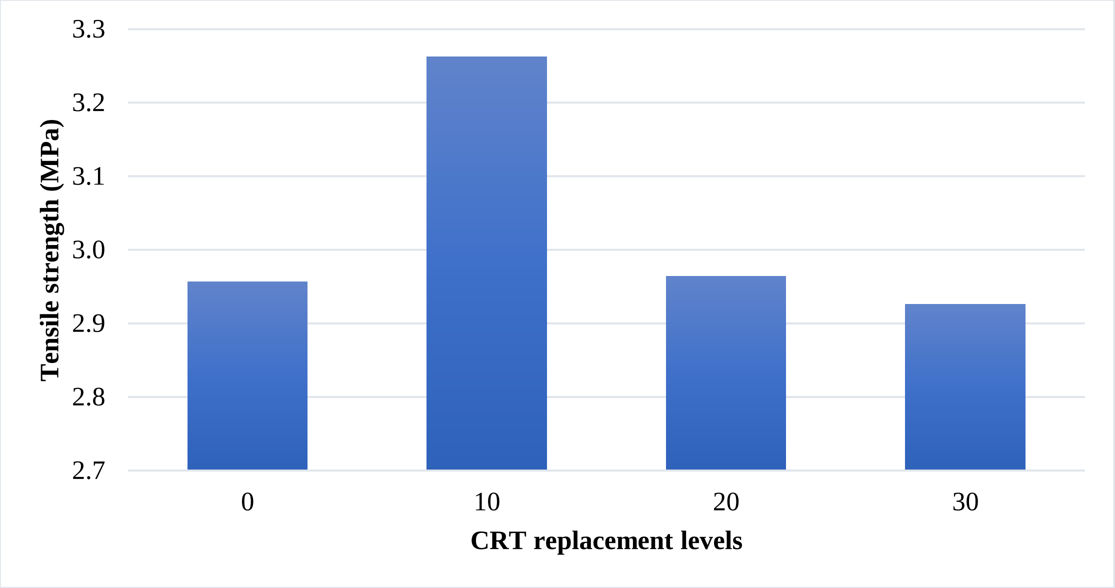

Fig.9: Splitting tensile strength of concrete specimens at different replacement levels at 28 days

Table 2 shows the relationship between compressive and tensile strength of the concrete specimens at 28 days. The control mix has the highest ratio of 9.4%, whereas the lowest ratio was for CRT10 mix at 8.6%. The range shows that the difference is very slight, and the values are reasonable.

Table 2: Ratio between compressive and tensile strength

Mix	Compressive strength	Tensile strength	Ratio (%)
CRT0	31.4	2.96	9.4
CRT10	37.9	3.26	8.6
CRT20	34.2	2.96	8.7
CRT30	32.8	2.93	8.9

3.5. Ultrasonic Pulse Velocity (UPV)

The UPV test values for concrete specimens at all curing ages are shown in figure 10. It is observed that the UPV of all concrete samples increased with the increase of curing period. Also, CRT10 mix has the highest velocity at all ages, which is compatible with compressive strength results. For example, at 28 days, CRT10 has 4854 m/sec velocity while the control mix has 4732 m/sec velocity. Difference between minimum and maximum UPV was 240 m/sec at day 1 and it shrunk to 118 m/sec by day 90.

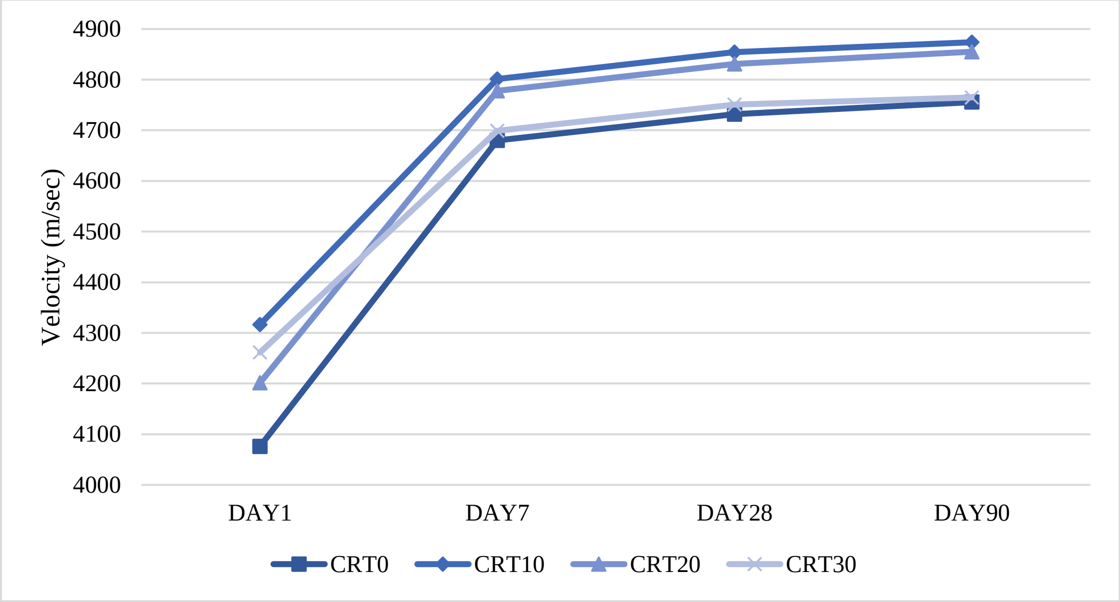

Fig.10: UPV values of concrete samples at different replacement levels and curing ages

3.6. Static Modulus of Elasticity

Figure 11 presents the static modulus of elasticity of the concrete specimens at 28 days. The elasticity modulus of concrete is 30.69, 34.33, 32.62, 31.44 GPa at 0, 10, 20, 30% replacement levels, respectively. These results are consistent with compressive strength output.

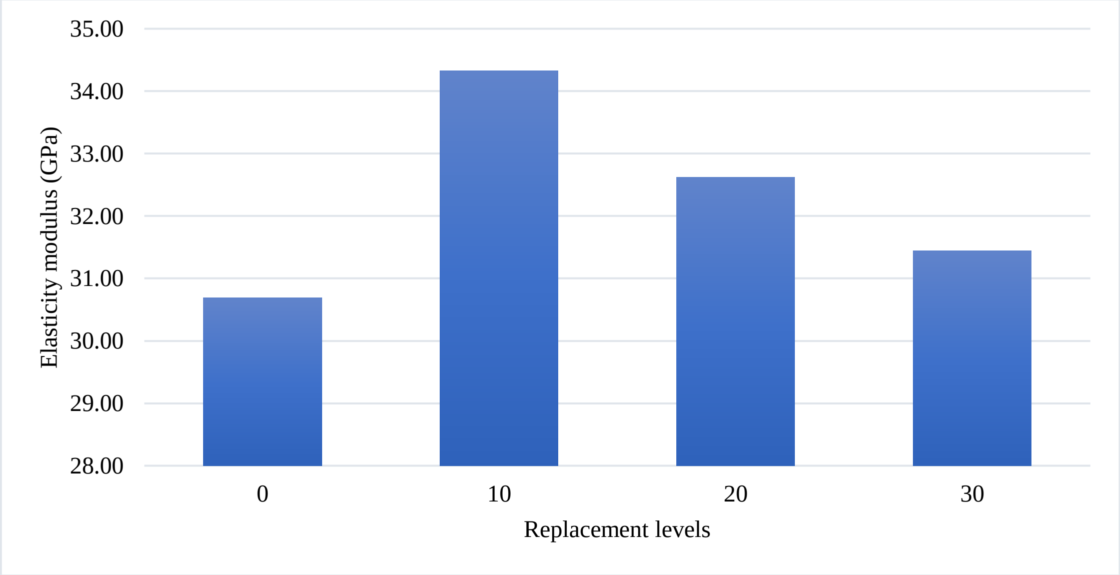

Fig.11: The 28 static elasticity modulus of concrete samples at different replacement

Figure 12 demonstrates the relationship between compressive strength and static modulus of elasticity. The following equation can be derived:

$$E = 5532\sqrt{F'c} \qquad \text{Eq. (4)}$$

Where (E) is the elasticity modulus in MPa and F'c is the compressive strength in MPa, both at 28 days. The formula indicates high correlation coefficient of R2=0.9601. This is conforming with a previous study (Zhao et al., 2013b). However, it is specified in the ACI 318-14 that modulus of elasticity can be computed by the equation (ACI 318, 2014) :

$$E = 4700\sqrt{F'c} \qquad \text{Eq. (5)}$$

This difference might be attributed to the difference in density between normal weight concrete and the concrete investigated in this study (Abdelgader et al., 2003; Rajabi et al., 2020).

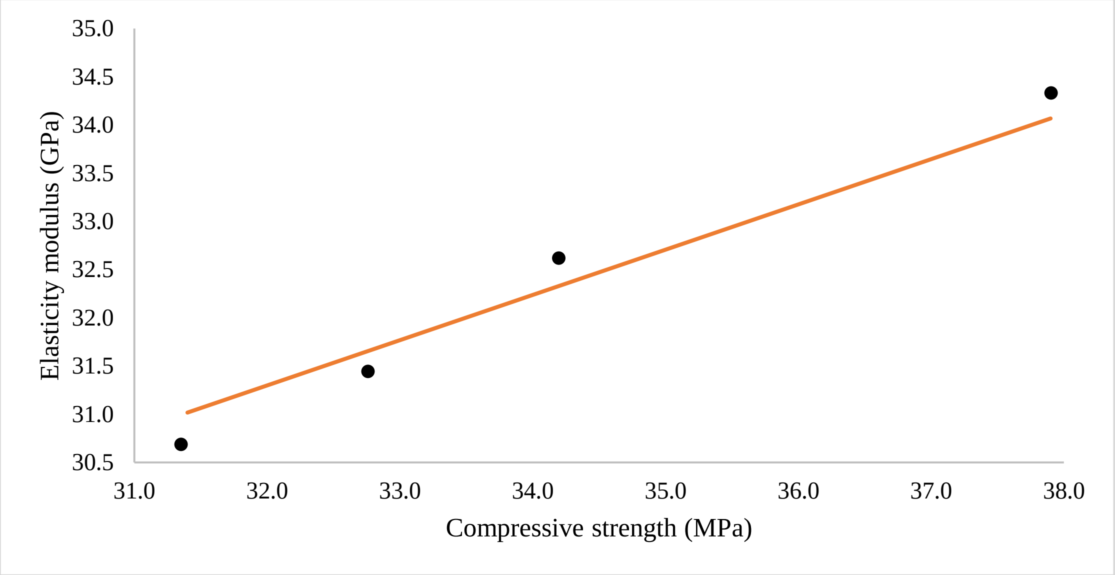

Fig.12: Relationship between compressive strength and elasticity modulus of concrete samples at 28 days

4. CONCLUSION

The objective of this study was to assess the effects of replacing natural sand by CRT glass at low replacement levels of 0,10,20, and 30%. The following conclusions can be derived:

1- Incorporating CRT glass improved the workability of concrete samples, as approximately same slump is maintained while lowering water reducer quantity for higher replacement levels. Using CRT glass saves SP.
2- The hardened density increased with the increase of CRT content due to higher specific gravity of CRT glass than that of sand.
3- Adding 10% CRT by volume increased compressive strength, tensile strength, and ultra-pulse velocity. However, these properties decline beyond this replacement level but maintain a higher value than control mix.
4- Elasticity modulus is proved to be decisively related to compressive strength, as it increased at 10% then dropped at 20% and 30% replacement levels.
5- It is recommended to investigate the feasibility of CRT in finer particle size than the one used in this study, to be utilized as a partial replacement for cement, for its richness in silica will probably produce satisfactory results in term of mechanical properties of concrete.

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