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PROCESSING OF CONSTRUCTION AND DEMOLITION WASTE FROM CONCRETE

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Abstract: There is a need to develop appropriate techniques and technologies that will upcycle construction and demolition waste as a secondary material. This study aims at improving construction and demolition waste from concrete. Three (3) fractions of materials were processed, jaw crusher and impact crusher were employed. Based on this study, the concrete construction and demolition waste fraction with raw material sizes between 45 to 80 mm, and 22 to 45 mm, could be explored for size range 4 mm to 25 mm (4/25) aggregates production, while the raw sizes 0 to 22 mm, could be investigated for 4 mm to 14 (4/14) aggregates after crushing and some selective sizing. Flakiness indexes were < 7% for the 2 larger size fractions. Further studies are recommended, on other properties.

Keywords: *construction and demolition waste, jaw crusher, impact crusher, aggregates*

1. INTRODUCTION

There has been an increased interest at a global level regarding the reuse and recycling of construction and demolition wastes (CDWs) (Contreras-Llanes *et al.* 2021). According to the European Environmental Agency (2023, last updated), CDW had a high recovery rate and stable amounts in the EU; however, management practices indicated that CDW recovery was largely based on backfilling operations and low-grade recoveries such as aggregates for road sub-base. Thus, there is a big potential for making CDW management truly circular. To increase the value and feasibility for CDW application, there is a need to develop proper up-cycling techniques. Extensive work has shown that plain and reinforced concrete debris can be crushed by primary or secondary crushers to produce recycled concrete aggregates within acceptable quality to BS 882 requirements (Limbachiya 2010).

The "equiaxed" nature for impact breaker is advantageous in concrete aggregates (Tarján, 1981). The advantage of vertical shaft impact (VSI) crusher is the ability to produce cubicle shapes, however this shape results in significant quantities of fines (Bengtsson and Evertsson 2006). In the study of Bengtsson and Evertsson (2006), the flakiness index (FI) from VSI crushed particles was around ½, those from the cone crusher and VSI speed have an influence on the FI, with higher speed producing lower FI. Besides, a higher velocity VSI increases the proportions of finer particles produced as compared to a lower velocity VSI. Hubert *et al.* (2023) conducted a study on recycled concrete aggregates and observed that the jaw crusher produced fewer fine particles as compared with the impact crusher. In addition, the impact crusher produced recycled concrete aggregates with less flakiness and shape index as compared with the jaw crusher. However, according to Ulsen et al. (2019), the recycled concrete aggregates end products for jaw and crusher processes were not significantly different with respect to adhered cement paste, density, porosity and particle size distribution. In other words, the differences did not justify the belief that the impact crusher has superior release ratios of recycled concrete aggregates. According to a study by Wang *et al.* (2024), impact crushing using a water jet for recycled concrete aggregates can result in deterioration of the interfacial transition zone (ITZ), and effectively remove the residual adhered mortar, which could further lead to residual adhered mortar and water absorption values being almost similar to natural aggregates. To improve the quality of recycled aggregates, further treatment could be explored. The study by Qiu *et al.* (2014), which involved microbial carbonate precipitate treatment, and that of Li *et al.* (2019) using carbonation treatment, both resulted in reduced water absorption of the treated coarse aggregates.

According to the Advancing Standards Transforming Markets (ASTM) International, ASTM D1883-21, the CBR test can be applied to several engineering applications, such as evaluating the potential strengths of subgrade, subbases, and base course materials, including recycled materials, for flexible roads and airfield pavement designs. Zhang et al. (2021) evaluated recycled aggregates having blended components, and noticed that the aggregate crushing value varied with the amounts of gravel, brick, and mortar. Furthermore, Martinez-Echevarria *et al.* (2020) observed that California Bearing Ratio (CBR) values for recycled aggregates increased after being submerged, an indication of anhydrous particles that reacted with water. They further noticed that crushing resulted in an increased hydration activity, which could imply that cement particles in the recycled aggregates come to the surface after crushing, and hence increased the hydration activity as well as support capacity increase.

Consequently, this paper systematically examined the impact of crushing on three fractions of concrete CDW in Hungary. Preparations and analysis were conducted at the University of Miskolc. Crushing was done by jaw and impact crushing. The aim of this research is to systematically process and classify CDW for concrete recycled aggregates and geopolymer precursor materials.

2. MATERIALS AND METHOD

Three CDW waste size fractions were classified based on raw particle size (feed sizes) and denoted as CDW I for the 45 - 80 mm, CDW II for the 22 - 45 mm and

CDW III for the 0 - 22 mm size ranges. This CDW from concrete waste with very minor impurities observed including wood/twigs. X-ray fluorescence (XRF) was used to determine the chemical composition and loss of ignition (LOI), and the result is presented in Table 1. Based on the results, the SiO_2 amounts arguably mainly from aggregates, CaO could be attributed to previous binders while LOI from carbonation.

Table 1

Chemical composition and LOI for the CDW materials by XRF.

	CDW III	**CDW II**	**CDW I**	**< 4mm, jaw crusher**
SiO_2	53.94	52.77	52.79	52.97
Al_2O_3	5.21	5.18	4.48	5.79
MgO	1.20	1.36	1.29	1.25
CaO	20.67	22.00	22.97	20.73
Na_2O	0.56	0.55	0.50	0.61
K_2O	1.28	1.21	1.00	1.43
Fe_2O_3	1.51	1.41	1.24	1.61
MnO	0.09	0.10	0.10	0.10
TiO_2	0.16	0.16	0.15	0.19
P_2O_5	0.08	0.08	0.08	0.09
S	0.75	0.91	0.91	0.81
LOI	14.47	14.2	14.41	14.34

2.1. CDW Sampling Preparation

To make the homogenized samples, quartering and/or mechanical splitting techniques were employed based on size to obtain representative samples for both short- and long-term use. Quartering was initially conducted for the 3 categories of concrete CDWs, then mechanical splitting was performed for the CDW III sample, using a 50 mm width splitter based on the largest size as per AASHTO R 76 (Washington State Department of Transportation 2023). Other fractions generally followed ASTM C702 and AASTHO R 76, as described in Gilson Company Inc.

2.2. Crushing and particle size distribution

The raw CDW II & CDW III particle size distributions were done by dry sieving. Sieves of up to 125 mm were used for CDW I, due to their larger sizes. Figure 1 illustrates the raw material particle cumulative undersize graph. A semi-industrial jaw crusher (PE 02 type) was used for CDW I (2 passes) and II (1 pass), then < 4mm was sieved off before the CDW I, II and III were crushed using a RTE 24/18 type horizontal shaft impact crusher, with a rotor circumferential speed of 30 m/s in all cases. Before the CDW material fractions were fed into the impact crusher, the < 4 mm sizes were sieved off. The CDW I and CDW II were crushed by the jaw crusher and impact crusher, whilst CDW III was crushed only by the impact crusher. The type and level of crushing were chosen based on the size-dependent classification. In other words, the CDW III was crushed only by the impact crusher due to its relatively small average particle size. CDW I was subjected to 2 passes jaw crushing with approximate spacings of 30 mm and 20 mm (peak to peak). The jaw crushing of CDW II fraction was passed through approx. 20 mm spacing (peak to peak). The cumulative undersize for ≥ 4 mm of jaw crushed and raw CDW III material before impact crushing is illustrated in Figure 2.

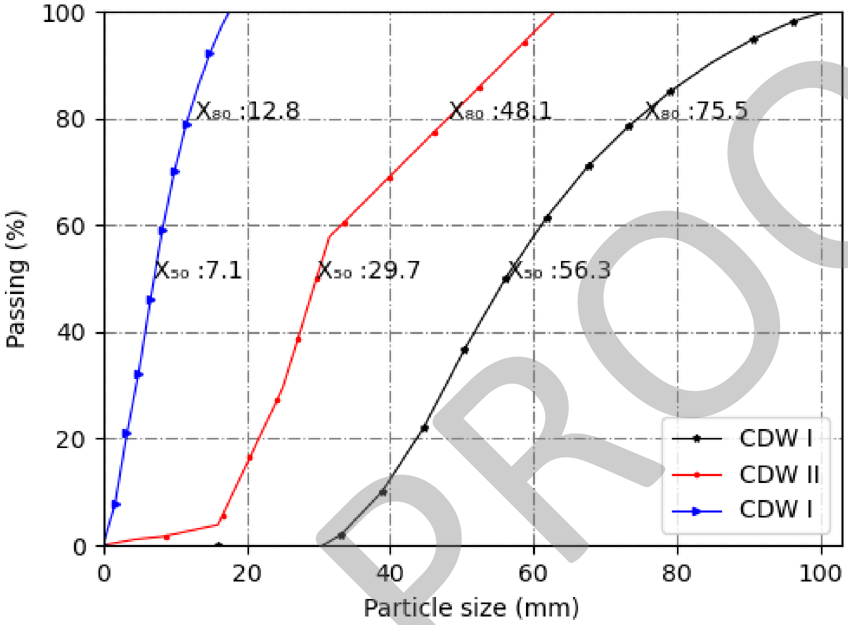

Figure 1

Particle size distribution for the CDW raw materials, sieve sizes of 125 to 16 mm, 6 fractions for CDW I, 63 to 4 mm for CDW II and 31.5 to 1 mm, 4 fractions for CDW III

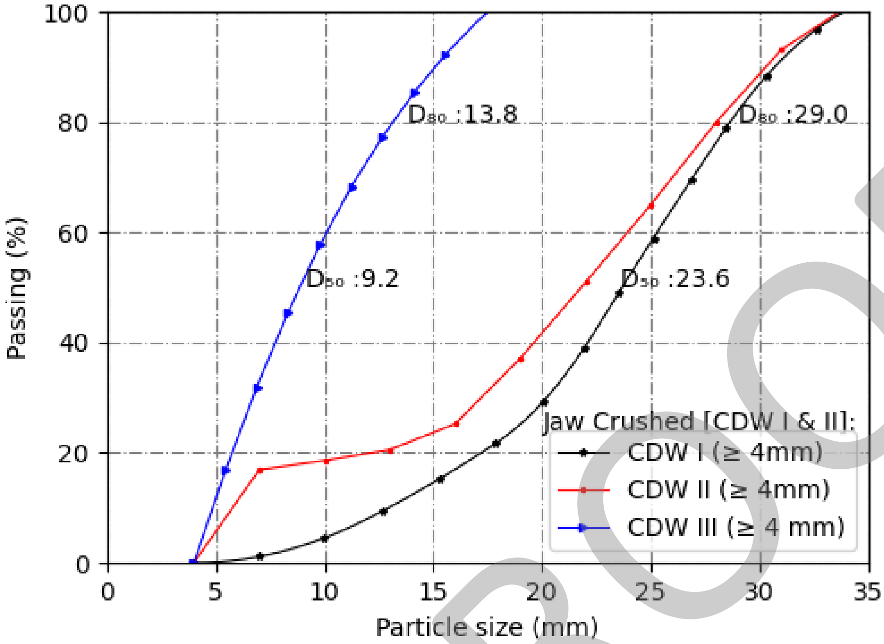

Figure 2

Particle size distribution for the CDW ≥ 4mm for CDW III and jaw-crushed CDW I & II, sieve sizes of 40 to 4 mm.

General crushing and classification steps are illustrated in Figure 3. The particle size distribution for materials with dry seiving, was conducted, with up to 125 mm sieve size, CDW I and CDW II raw materials, for CDW III raw materials dry sieving was up to 31.5 mm. The primary sieve sizes were based on ISO-3310.2 and ISO-3310.1.

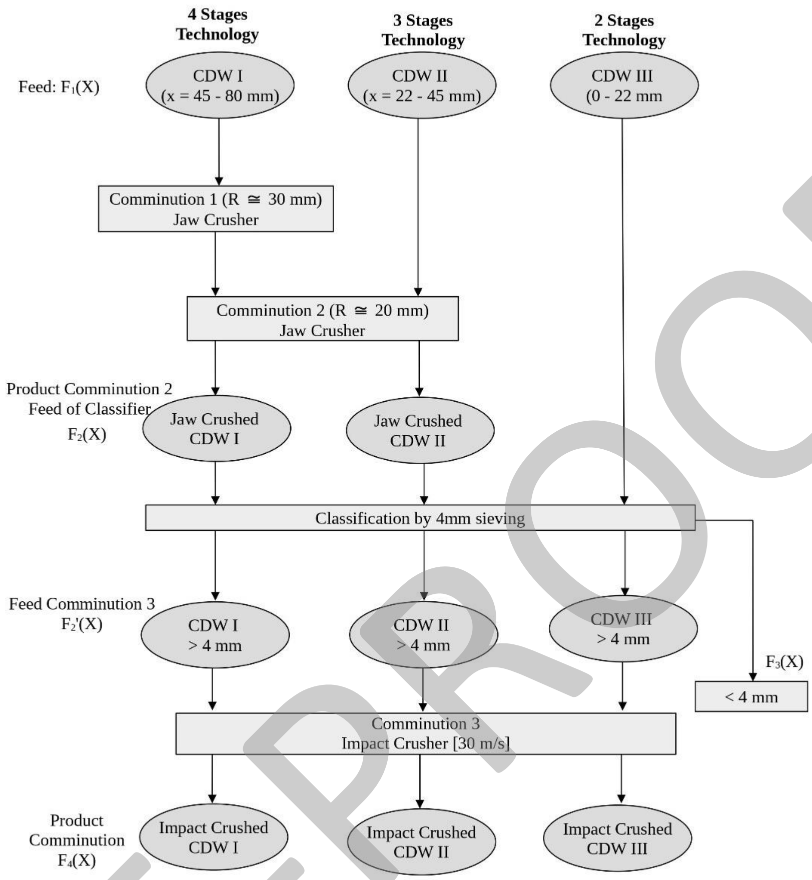

Figure 1: Flow sheet of CDW with different feed sizes

Figure 3

Flow sheet for crushing the CDW I (45-80 mm size), CDW II (22- 45 mm size) & CDW III (0 – 22 mm size).

2.3. Flakiness Index

The flakiness index (FI) was conducted for aggregates CDW I and CDW II for sizes > 4 mm in this study. Based on the slot widths and particle size fractions according to European standards EN 933-3: 2012, whereby the slot widths are ½ the size of the particle size sieve passing the respective fraction. All the aggregates were assumed to be in a dry condition, within an enclosed laboratory.

$$FI = \frac{M_p}{M_T} \tag{1}$$

where M_P and M_T are the mass passing the slots, and the total mass of the respective fraction.

3. RESULTS

Particle cumulative undersize for the impact crushing products are illustrated in Figure 4 and 5, for CDW I, CDW II, and CDW III after impact crushing, also curved developed based European standards limits SIST EN 12620: 2013, for categories G_c 80/20 and sizes 4 mm (d) to 25 mm (D) i.e. (4/25) in Figure 4 and G_c 80/20 and sizes 4 mm to 14 mm (4/14) in Figure 5. G_c represent 80% passing lower limit size D and 20% passing upper limit size d.

In addition, Figure 6 presents the cumulative undersize of CDW IV, which is a mixture of CDW I, II & III for sizes < 4 mm and sieved from the impact crusher feed. The Figure 4 curves for CDW I and II against the 4/25 sizes had higher finer particles, the coarser proportions were within the limits. After removal of ¾ material of < 4 mm, the adjusted curves [denoted: ADJ] fitted the limit-based curves. The removed material represents 20.7% and 18.9% of the initial impacted crushed material for CDW I and CDW II, respectively. The Figure 5 curves for CDW III, the 4/14 sizes had higher finer particles, with coarser proportions generally within the limits, after removal of < 20 mm (2.18% of total crushed) and ¾ for < 4 mm portion (23.2% of total crushed), the ADJ curve fitted. Figure 6, the < 4 mm sieved from the 3 fractions, after jaw crushing CDW I and II and raw CDW III, the passing 50% and 80% i.e. D_{50} and D_{80} were 1.6 mm and 3 mm, showing an almost constant steepness from ≥ 60% undersize and relatively steeper at ≤ 20% undersize.

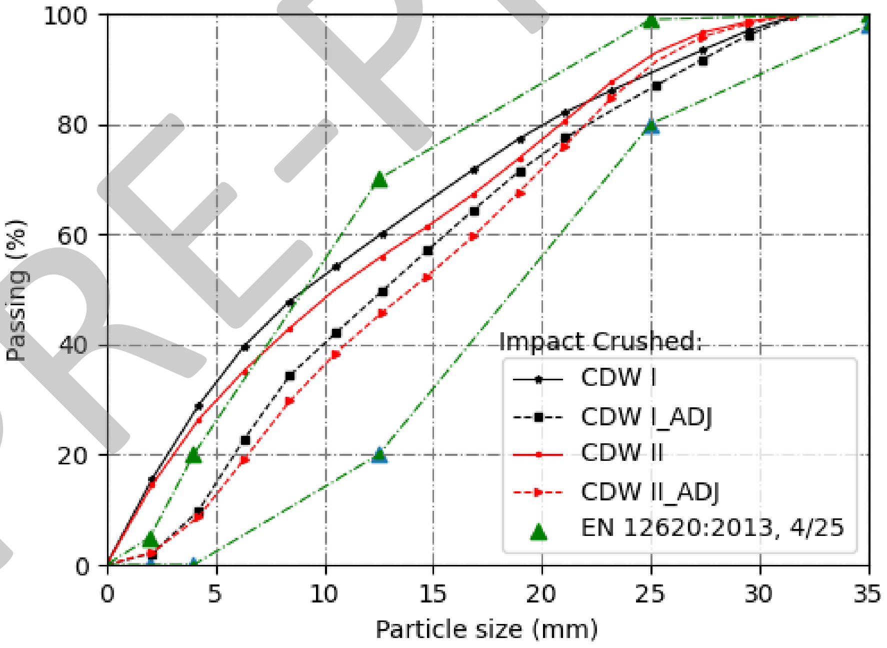

Figure 4

Particle size distribution for CDW I and II impact crushing products, sieve sizes of 40 to 4 mm, and 8 size fractions for CDW I and 10 for CDW II

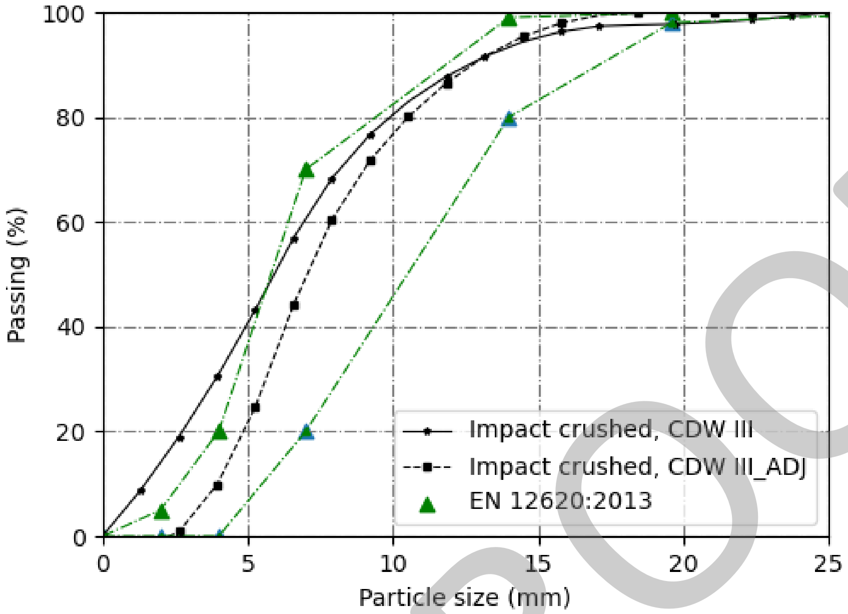

Figure 5

Particle size distribution, CDW III products after impact crushing with sizes ranging from 25 to 4 mm, and 7 size fractions

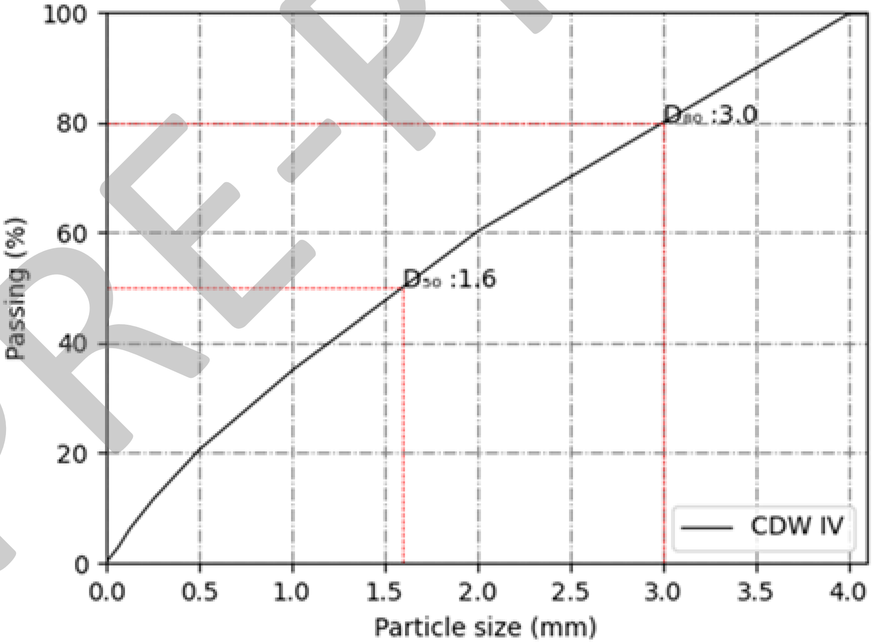

Figure 6

Particle size distribution for CDW IV with sizes <4mm from impact feed, sieve sizes of 8 to 0.063 mm, and 8 size fractions

Reduction ratios for 50% passing (r_{50}) and 80% passing (r_{80}), for the jaw crusher and impact crusher (30 m/s) are as illustrated in Table 2. Moreover, Figure 7 shows the jaw-crushed sample and Figure 8 illustrates the samples after impact crushing, with a visible size reduction. Based on those Figures, size reduction occurred for CDW I and CDW II after impact crushing and an increase in finer particles.

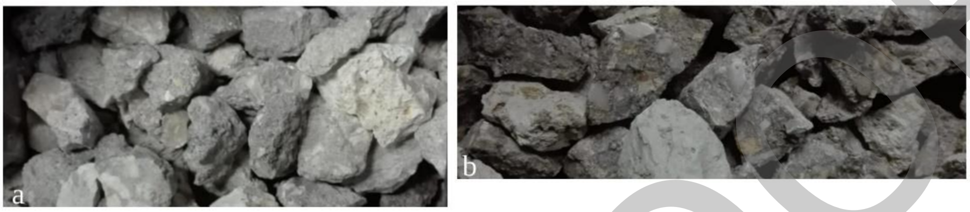

Figure 7
Jaw crushed concrete waste sample a) CDW II and b) CDW I.

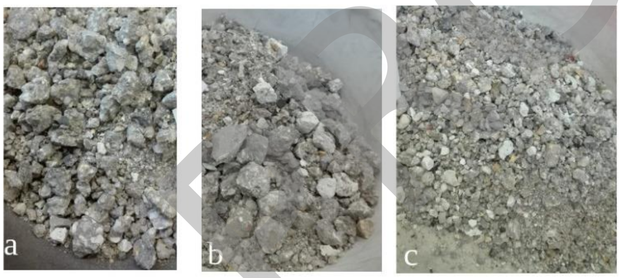

Figure 8
Impact crushed concrete waste at 30 m/s sample a) CDW I, b) CDW II, and c) CDW III.

Table 2
Reduction ratios at passing 50% (r_{50}) and 80% (r_{80}) for the jaw and impact crushers at 30 m/s.

	CDW I		**CDW II**		**CDW III**	
	r_{50}	r_{80}	r_{50}	r_{80}	r_{50}	r_{80}
Jaw Crushed	2.5*	2.6*	1.4	1.7		
Impact Crushed	2.6	1.4	2.1	1.4	1.5	1.4
****Total**	**6.1**	**3.8**	**2.8**	**2.3**	**1.2**	**1.3**

*2 passes; ** 4 mm classifier before feeding into the impact crusher, hence the feed ≥4 mm.

The FI, for ≥ 4 mm is presented in Table 3 for CDW I & II, the maximum at 6.11%, based on the results, CDW I improved, from 6.11% to 3.23% after impact crushing but CDW II had just a marginal change/decline from 3.14% and 3.62%.

Table 3

Flakiness index (FI) for jaw crushed and impact crushed CDW I & CDW II

	CDW I		**CDW II**	
	Jaw crushed	**Impact crushed**	**Jaw crushed**	**Impact crushed**
FI	6.11%	3.23%	3.14%	3.62%

4. DISCUSSION AND CONCLUSIONS

The sampling preparation undertaken in this study proved very important as it ensured consistency in the CDW material. Furthermore, the size reductions achieved after crushing the CDW samples helped in the categorization of the samples into various aggregate categories suitable for different applications. The CDW I and CDW II reduction ratios (r_{50}) were 6.1 and 2.8 for the jaw crushing, 4 mm classifier, and impact crushing, respectively and r_{80} of 3.8 and 2.3, respectively. Hence, almost a similar reduction ratio, with CDW I being marginally higher, could be due to the slightly higher raw material sizes for the larger particles (> 80 mm) and 2 passes for CDW I. There was not much difference between the CDW I and CDW II product sizes, the closeness of the reduction ratio value could indicate the similarity of properties for both factions. The CDW I and II lower and higher fractions were not within the 20 mm maximum limit curve ranges, however, the D_{50} were within the range. The CDW III was marginally not within the 10 mm maximum limit curve range.

Visibly, the aggregates produced by the impact crusher had regular shapes with reduced sharp edges. The FI for CDW I and II were below 4 % after impact crushing and below 6.11% after jaw crushing, showing that the jaw and impact crushing aggregate shape could be suitable for concrete application. According to a study by Ulsen *et al.* (2013), impact crushing affected the sphericity of CDW-sand and rock-to-rock crushing, resulting in improved morphology.

According to Moreno-Juez (2021), higher LOI for CDW in comparison to cement was attributed to calcite content in the CDW. The Federal Highway Administration Research and Technology (USA) described the maximum LOI at 6% for fly ash or natural pozzolans as a Portland cement admixture. Moreover, according to ASTM C618-92a requirement, high carbon content (high LOI) results in a negative impact on air entrainment. In this study, the LOI values are in the range of 14 – 15 %, in Table 1 which are significantly higher than the allowable limits of ordinary Portland cement (OPC). Based on the LOI, utilization of CDW binder from this study should be a consideration, particularly for the longer-term or durability concrete properties. Also, the study recommends further CDW binder's LOI control studies.

In a nutshell, this study underscores the significance of initial systematic preparation and characterization of recycled aggregates, however, there is a need to pursue further studies such as surface treatment and other properties. Further treatment is required to clean up the adhering mortar. This further treatment, coupled with selective material sizing can be considered for the CDW 4/14 and 4/25 mm coarse aggregate production. Besides, the CDW fines ($\geq$ 4 mm) from the classifier can be further processed for utilization as a concrete binder in future research. This study recommends additional property tests and further research to improve the quality of recycled aggregates including chemical or mechanical treatment.

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