The Influence of Recycled Concrete Aggregate on The Carbon Footprint of Concrete

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Abstract - The industrial sectors around the world have resorted to the use of recycled materials to reduce environmental impacts and enhance sustainability. The utilisation of recycled concrete aggregate for concrete production will greatly decrease the demand for natural aggregate as well as lower the amount of construction and demolition waste that will be sent to the landfill. The severity of the issue of global warming has increased the interest from the construction industry to determine and control the amount of greenhouse gases associated and generated by concrete production and construction activities. The impacts of recycled concrete aggregate on the mechanical properties of concrete have been investigated over the years with specific recommendations and replacement percentage reported to improve performance. This paper reviews the CO_2 emission of recycled aggregate concrete based on investigations conducted by researchers. Recycled aggregate concrete was concluded to lower the amount of CO_2 emission and resulted in more reduction when other waste materials like silica fume, fly ash, and GBBS was added as admixtures.

Indexed Terms- Recycled Concrete Aggregate, Global Warming, CO_2 Emission, Recycled Aggregate Concrete, Construction and Demolition wastes.

I. INTRODUCTION

The effect of global warming has reached crucial levels with the average global temperature increased by 0.6ºC in the last century. The next century is also estimated to encounter a rise between 1.4 ºC and 5.8 ºC (Department for Environment, Food and Rural Affairs, 2004). To address this issue, the International Kyoto Protocols and National Climate Change Acts around the world has agreed and aims to cut down the emission of CO_2 by at least 100% of 1990 levels by 2050 (Environmental Data Interactive Exchange,2014).

The major contributor to the emission of CO_2 which consequently contributes to environmental damage is Portland cement. Portland cement is one of the significant constituents of concrete and it is extensively utilised in the construction industry. Other components such as coarse and fine aggregate also play a vital role towards attaining good quality of concrete. The significance of these natural materials coupled with an increased demand for buildings and infrastructure has resulted to the depletion of natural resources which are non-renewable thus leading to adverse environmental and economic consequences (Meddah et al, 2020). The concrete construction industry has resulted in the utilisation of various supplementary cementitious materials (SCM) like fly ash, silica fume, and granulated blast-furnace slag in conformity with BS EN 197-1 (British Standard institution, 2011) which are more environmentally friendly and can consequently decrease the concrete CO_2 emissions.

The global construction industry has been estimated to consume 48.3 billion tonnes of aggregates annually (Concrete Construction, 2012). Thus, the importance of producing sustainable concrete in the construction industry by reducing the utilisation of raw materials cannot be over emphasised. Data compared from 24 developed countries by Vivian et al,(2018) revealed that they are keen to encourage and promote the utilisation of different recycled aggregates through newly introduced legislations aimed at reducing landfills and limiting extraction of natural resources**…** The significance of using recycled coarse aggregate for concrete production stems from its positive environmental influence by minimising landfills and decreasing the demand on mineral extraction. However, some of the limitations of using recycled aggregate include; customer perception, limiting specifications and standards, a large variation in the quality of recycled concrete, and distance of construction and demolition waste (CDW).

Carbon footprint was initially expressed through the area needed to assimilate CO_2 emissions generated by a product throughout its lifetime. However, with the severity of global warming, the carbon footprint is expressed as the quantity of greenhouse gases associated and generated by a service or product throughout its lifetime (Jimenez, et al 2018). (Wiedmann and Minx, 2008) Defined carbon footprint as the weight in tons or kilogram, of greenhouse gas emissions per product, activity or person, for which an emissions inventory is required. The carbon footprint is therefore an important tool to evaluate the impacts of concrete production on the environment. In view of the diversity and variability of the properties of recycled concrete aggregate, researchers have actively investigated methods and remedies to improve the mechanical properties of the resulting concrete. It is therefore necessary that the feasibility of this material is further investigated through life cycle assessment with carbon footprint as the element of focus. This paper will review the influence of recycled concrete aggregate on the carbon footprint of concrete based on the investigations carried out by researchers and proffer recommendations for future research.

II. PROPERTIES OF RECYCLED CONCRETE AGGREGATE

Recycled concrete aggregate is obtained from crushed construction and demolition waste majorly consisting of concrete and materials like slag, crushed stones, and glasses. The crushed concrete is then refined to remove impurities and further fed into a crushing machine to achieve specific aggregate sizes. An understanding of the properties of this aggregate will improve knowledge on its performance in the new concrete.

The shape of aggregates influences the workability of concrete. In view of this, it is significant that the shape of recycled concrete aggregate achieve acceptable standards for use in structural concrete. The hard edges of the original aggregate can smoothen out by the residual mortar of recycled concrete aggregate resulting in an improved workability of the concrete (McNeil and Kang, 2013). It was confirmed Sagoe-crenstil et al (2001) where plant produced recycled aggregate was described to have a more rounded, spherical shape. The gradation curves for recycled concrete aggregate has been reported to be within the specified range of standards for concrete aggregate making it suitable with acceptable gradation and no necessary adjustments. (Crentsil et al. (2001) and Shayan and Xu (2003))

The Porosity, water absorption and density of recycled concrete aggregate are important characteristics needed to obtain a proper concrete mix. These properties will influence the amount of recycled aggregates utilised to limit the absorption capacity to a maximum 5% for structural concrete. The adhered motar on recycled concrete aggregate has higher porosity compared to natural aggregate which result in more water retention within its pores. Shayan and Xu (2003**)** reported a difference in water absorption values of up to 4.2% with a range 4-4.7% for recycled concrete aggregate and 0.4-1% for natural aggregate. The adhered mortar on recycled aggregate concrete can be lightweight compared to natural aggregate of same volume and this will influence the density. Sagoe-Crentsil et al. (2001) reported a 17% difference in bulk densities of recycled concrete aggregate and natural aggregate with values of 2394 and 2890 kg/m^3 respectively.

III. CARBON FOOTPRINT OF RECYCLED AGGREGATE CONCRETE

Researchers around the world have investigated and reported the advantages of using recycled aggregates in the reduction of greenhouse gases.

Jimenez et al. (2018) recovered debris from structural elements like beams, slabs and columns for use in the production of concrete that will be investigated to ascertain the carbon footprint in comparison with concrete containing virgin coarse aggregate. Two sets of mix with percentage replacement of 0, 25, 50, and 100% were prepared for water-cement ration of 0.5 and 0.7. The values of carbon emission ranged from 347 – 351 kg/m^3 for concrete with 0.5w/c and 261 - 265 kg/m^3 for concrete with 0.7w/c. similar research conducted by Turner and Collins (2013) under similar conditions showed a slighted higher value of 354 kg/m^3 for concrete with 0.6 w/c. The damage of this emission to human health was further assessed while considering 1kg of carbon emission to represent 2.1 x10^{-7} DALY. This represents disability-adjusted life year which is the number of years lost due to disability, lack of health, or premature death (Goedkoop and Spriensma, 2011). The DALY value obtained ranged between 7.29 – 7.36 x 10^{-5} (38.5 minutes) for concrete with 0.5w/c and 5.49 – 5.56 x 10^{-5} (29 minutes) for concrete with 0.7w/c.

Mixture		Fc	Cement	Aggregates	Others	Partial	Total
w/c	%R						
0.5	0	32.5	305.5	44.6	0.61	45.2	350.7
0.5	25	31.6	305.5	43.9	0.55	44.4	349.9
0.5	50	30.8	305.5	43.1	0.49	43.6	349.0
0.5	75	29.8	305.5	42.3	0.44	42.7	348.2
0.5	100	29.8	305.5	41.6	0.38	42.0	347.4
0.7	0	23.7	218.3	45.8	0.63	46.4	264.7
0.7	25	23.1	218.3	45.0	0.57	45.6	263.9
0.7	50	22.5	218.3	44.2	0.51	44.7	263.0
0.7	75	21.0	218.3	43.5	0.46	44.0	262.2
0.7	100	19.0	218.3	42.7	0.41	43.1	261.4

Table 1: CO_2 Emissions,
Source: Jimenez et al. (2018)

Comparative carbon emission assessment on natural and recycled aggregate concrete was conducted by Sabau et al, (2021). Detailed insight in the life-cycle assessment parameters were obtained by carrying out sensitivity study in which different values of natural aggregate to recycled aggregate ratio (25 -50%), case specific transportation distance and supplementary cementitious materials were considered. Carbon emissions between 323 and 332 kgCO_2e was recorded for concrete incorporating natural aggregate and cement without fly ash and adopted as the reference for global warming potential. A reduction of about 17% can be obtained when cement is replaced with fly ash up to 25%. The transportation distance of recycled concrete aggregate also influenced carbon emission leading to an increase of 0.3% and 3.4% for normal and high strength respectively when incorporated to replace natural aggregate by up to 50%. This increase in emission intensified as the replacement percentage also increased to 100%. The incorporation of fly ash by up 25% and utilization of 100% recycled concrete aggregate produced a lower carbon emission compared to concrete made with natural aggregate and cement. However, the incorporation of fly ash in the later will also yield a much lower emission compared to that of recycled aggregate concrete.

The incorporation of other waste materials like silica fume (SF) and ground granulated blast-furnace slag (GGBS) has also been shown to lower carbon emission in recycled concrete manufactured with 100% recycled concrete aggregate in a research conducted by Mouna et al, (2021). The estimation of carbon emission was conducted on three different mixes with 0% recycled aggregate, 100% recycled aggregate and 100% recycled aggregate with SF and GGBS. While taking into consideration the cement production phases, the production of both fine and coarse aggregate as well as a transportation distance of 400km; carbon emission values of 425, 400, and 249 kg CO_2eq/m^3 was reported. This indicate a 40% decrease in emission when natural aggregate is totally replaced with recycled concrete aggregate and cement replaced with 50% GBBS and 10% SF. Without any admixture, the concrete mix containing 100% recycled aggregate also displayed a lower carbon emission by 5% which followed similar trend as the study conducted by Imtiaz et al, (2021).

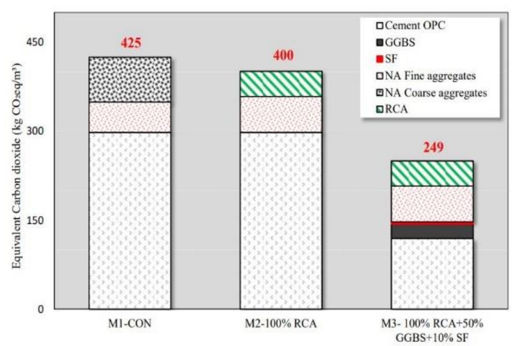

Figure 1: Equivalent CO_2 (kg CO_2e/m³) emissions for concrete mixes,
Source: Mouna et al, (2021).

The investigation was carried out using recycled aggregate concrete (RAC), Recycled aggregate-based geopolymer concrete (RAGC) and geopolymer concrete (GPC) where they reported a higher global warming potential (GWP) in ordinary portal cement concrete compared to the three mixes RAC, GPC and RAGC. The CO_2 emission follows a decreasing pattern as shown in Figure 2 (Imtiaz et al, 2021). However, the study by Sabau et al, (2021) does not follow similar trend with the introduction of recycled concrete aggregate. This can be attributed to varying conditions like transportation distance and w/c ratio.

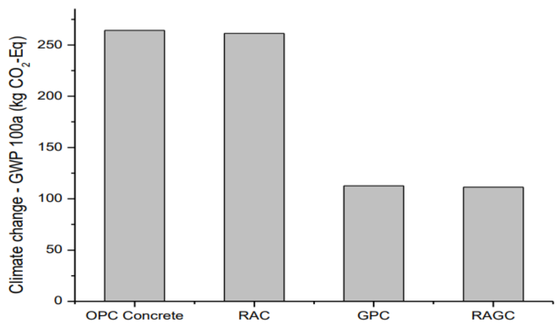

Figure 2: CO_2 Emissions of the four mixes, Source: Imitiaz et al, (2021)

CONCLUSION

This paper reviews the influence of recycled concrete aggregate on the carbon footprint of concrete. The conclusions outlined are drawn based on findings from previous research.

- Recycled concrete aggregate has been shown to lower the amount of carbon emission when utilised in concrete as replacement for natural aggregate. The addition of other waste materials (Admixtures) like fly ash, silica fume and GGBS which has also been reported to improve mechanical performance of concrete resulted in a further reduction in the amount of CO_2 emission. This indicates that the addition of certain admixtures can aid the production of recycled aggregate concrete with improved performance and less carbon emission.

- The transportation distance of recycled concrete aggregate from plant to site and cement content has shown to negatively influence the carbon emission of the resulting concrete. These make it significant to source locally available recycled concrete aggregate with shorter distance and investigate more supplementary cementitious materials that can replace the cement content within the concrete without negatively affecting its mechanical properties

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