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Comparative Analysis of Life Cycle Assessment of Conventional Concrete by Partially Replacing Cement by Fly Ash with the Inclusion of Carbon Nanotube

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***Abstract*— The construction of building uses a lot of natural resources as raw material for making of concrete, which uses a lot of energy and pollutes the environment on larger scale. This concrete making contributes significantly to environmental problems worldwide, mainly due to the high emissions involved in cement production. Using OpenLCA software and the Ecoinvent database, a life cycle assessment carried out to examine concrete environmental performance by partially replacing cement by fly ash and further inclusion of carbon nanotubes. In this study three M40-grade concrete mixtures were examined, M40CC, M40CFA, and M40CFACNT. The results demonstrate that partially using fly ash significantly mitigates environmental effects of cement production especially when it comes to GWP. The carbon footprint of M40CFA was 38% lower than that of M40CC. M40CFACNT gives better conventional concrete results. This research indicates that use of waste materials like fly ash can encourage the production of more environmentally friendly concrete solutions.**

***Index Terms*— Carbon dioxide, carbon nanotubes, Portland cement, Ecoinvent, life cycle assessment, sustainability.**

I. Introduction

Now a days concrete is the one of the most widely used building materials in the world, and therefore for resource depletion and climate change, its effects on the environment are becoming an issue of concern[1], [2]. The concrete production, which includes energy-intensive processes and the use of non-renewable resources, contributes particularly] to global environmental issues, involving greenhouse gas emissions, fossil fuel consumption, and resource depletion.[3], [4], [5] Now a days identifying methods for sustainable construction material, for greener alternatives in concrete mix design is need.[4], [6], [7].
In this we prepare 3 mixes first concrete mix is a conventional M40 grade of concrete (M40CC). The second one with mix includes a 40% replacement of cement with fly ash (M40CFA). The third mix also contains a 40% cement partial replacement with fly ash, along with the addition dose of 200 ml/m3 carbon nanotube (CNT) and Visco Flux 2203+ as a superplasticizer 0.7% by weight of cement (M40CFACNT).

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The Visco Flux 2203+ superplasticizer increases the performance of the concrete, making it a high-performance mix. Ordinary Portland cement (OPC 53) grade is used for all mixes to achieve optimal strength.[8], [9], [10], [11], [12]

The three different M40 concrete design mixes 1 m3 quantities are used to compare the environmental impact of M40CC, M40CFA, and M40CFACNT. These mixes binding materials involving cement, coarse aggregate, fine aggregate, fly ash, carbon nanotube, and superplasticizers.[5], [7], [13], [14], [15], [16] The goal of life cycle assessment (LCA) is to calculate the environmental impact of each mix, with the pointing on the cradle-to-gate phase, which surrounds the extraction and processing of raw material, energy consumption during production, and transportation footprint.

The Ecoinvent database is used to provide environmental footprint values for energy sources and materials. The environmental impact is evaluated using the ReCipe 2016 (midpoint H) method which involves impact categories such as global warming potential (GWP), water consumption, air pollution, fossil fuel depletion, and human toxicity. This is to determines which concrete mix is the most environmentally friendly and still performing well by analyzing the environmental impact of 1 m^3 of each mix.[17], [18], [19], [20], [21]

The Life Cycle Assessment (LCA) of the 3 mixes analysis is used to evaluate environmental characteristics of concrete structures during their entire life cycle.[20], [22], [23], [24]

II. Materials and Methods

Cement OPC 53 grade from local shop Nagpur, fly ash is procured from Koradi thermal plant, Koradi, District Nagpur, CNT, procured from Eden Innovations India Pvt Limited, Superplasticizer Visco Flux 2203+, Procured from Apple Chemie India Private Limited, Nagpur.[25], [26]

A Life Cycle Assessment (LCA) approach to compare the environmental impacts of three concrete mixes M40CC, M40CFA, and M40CFACNT with addition of superplasticizer. The goal is to determine which mix is more environmentally friendly while maintaining good performance. The comparison is based on the 1m^3 of concrete. We calculate the environmental impact of each material needed to produce this volume. The study covers the cradle-to-gate phase which includes extraction and processing of raw materials (cement, fly ash, aggregates, CNT, and water), energy use in production (electricity) and transportation of materials to the production site. The material quantities for each mix are determined using mix design standards (IS 10262 & IS 456:2000. [27], [28] The main components include cement, fly ash, CNT and superplasticizer, which act as binding materials. Fine and coarse aggregates, such as sand and gravel, provide strength to the mix. Water and electricity are essential for the mixing and production process. For the analysis of all three mixes, electricity consumption was considered 0.82 kWh per m^3 of concrete, with transportation distances set at 30 Tkm (Tonne Kilo meter) for coarse aggregates and 50 Tkm for fine aggregate.[29], [30], [31]

The quantity of raw components for each 1m^3 of mix is determined from mixed design calculations in accordance with IS 10262:2019 and IS 456:2000, mentioned in table number 1[27], [28], [32], [33]. The standard Life Cycle Inventory (LCI) database Ecoinvent provides environmental impact values for each material and energy source. The environmental footprint of each concrete mix is assessed using ReCiPe 2016 (Midpoint H) method, This method calculates the impact in different categories, including GWP (kg CO_2-equivalent) which shows how much each mix contributes to climate change, Fossil Fuel Depletion (kg oil-equivalent), which indicates how much non-renewable energy is used, water Consumption (m^3) which shows amount of freshwater used in production, air pollution (kg PM2.5-equivalent) which includes impact of dust and fine particles on human health and human toxicity (kg 1,4-DCB-equivalent) which indicates Harmful chemical emissions affecting people. Each mix's environmental impact is calculated based on the material quantities, energy used, and transportation distances.[34], [35]

TABLE I: MATERIAL CONTENT OF EACH CONCRETE MIX DESIGN

Materials	M40 Conventional concrete (kg/m3)	M40 Concrete with 40% Fly ash(kg/m3)	M40 Concrete with 40% Fly ash and CNT admixture + superplasticiser 0.7% by weight of cement (kg/m3)
Cement	445.53	240	297
Fine Aggregate	637.20	734	648
Coarse Aggregate	1170	1123	1096
Water	191.58	160	173
Fly ash	-	160	198
CNT	-	-	200ml
Superplasticizer	-	-	2.1

The findings help us choose the best option that is both good for the environment and works effectively. Based on the results, recommendations are made for greener construction practices, such as increasing fly ash use to reduce further environmental impact

III. RESULTS AND DISCUSSIONS

Comparative analysis of the impact assessment of three M40 concrete variants: M40CC, M40CFA and M40CFACNT [36]. In figure.1, shows that all impact categories are improved when supplementary materials are added. In climate change impacts, M40CFA reduced over 23% and M40CFACNT reduced 38% compared to M40CC, proving fly ash improves performance.

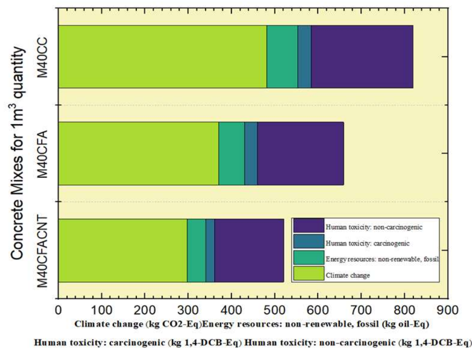

Figure 1. Comparison of Different Impact Categories

A decline in energy resource consumption (non-renewable, fossil) showed a similar trend with M40CFA at 14.89% and M40CFACNT 39.38% greater than M40CC. For the acidification (terrestrial), M40CFA and M40CFACNT contributed with a reduction of 18.73% and 39.90%. For human toxicity impacts (non-carcinogenic), a decrease of 15% was ob-served for M40CFA with M40CFACNT reducing 31.85% for M40CC. Carcinogenic toxicity impacts were reduced by 5.69% from M40CFA and 36.98% from M40CFACNT. These obtained results prove that adding fly ash and carbon nanotubes increase performance while lowering environmental impacts, the best option being M40CFACNT.

A. Acidification

The acidification potential of three different concrete mixes M40CC, M40CFA, and M40CFACNT is evaluated in terms of contributions from clinker production, electricity, diesel combustion, hard coal mining, blasting, and coal shown in figure.2. Among these, clinker production was the leading contribu-tor to acidification across all mixes. In comparison to M40CC, reductions were prominent with M40CFA and M40CFACNT. For clinker production, acidification impact reduction of 30.94% with M40CFA and 33.41% with M40CFACNT was observed. Hard coal mining impact reductions were 29.31% and 34.48%, respectively. Blasting contributions were similar; reductions of 27.5% with M40CFA and 32.5% with M40CFACNT. Diesel combustion reductions were small, yet notable at 3.57% and 21.43%, respec-tively. Lesser changes were noted in electricity, with no change in M40CFA and a reduction of 19.40% in M40CFACNT.

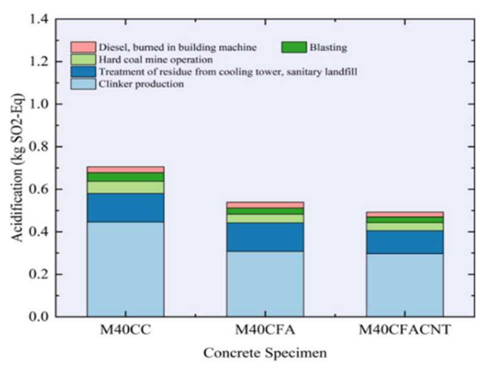

Figure 2. Acidification impact contributors among different mix.

It is visible from these result that substituting cement for fly ash and adding carbon nanotubes reduces acidification potential remarkably, especially because of decreased reliance on clinker and other fossil fuel intensive
processes.

B. Climate Change

The climate change impact of the concrete specimens shown in figure.4, expressed in terms of kg CO2-equivalent, shows a substantial reduction with the use of fly ash (CFA) and carbon nanotubes (CNT). The most conventional mix (M40CC) has the highest impact, valued at approximately 319 kg CO2-Eq. This was primarily due to the amount of clinkers produced. The inclusion of CFA in M40CFA brought down the impact by 30.9%. In addition, the CNT incorporation in M40CFACNT brought a total additional reduction of 33.4%. Overall, the total impact was reduced to 220.7 kg CO2-Eq for M40CFA and further to 212.8 kg CO2-Eq for M40CFACNT. Significant lesser contributions from hard coal mining along with its transport also brought significant decreases. Usage of natural gas also resulted in a 35.3% reduction for M40CFA and 42.3% for M40CFACNT usage. Hard coal operations showed a reduction of 29.6% with further decline of 34.2% thereafter. The CNT enhanced mix also marked a decrease of 32.4% in transport emissions. Figure.3 has demonstrated that adding additional cementitious materials in addition to nanomaterials minimizes the climatic impact of concrete by reducing the requirement for fossil fuels.

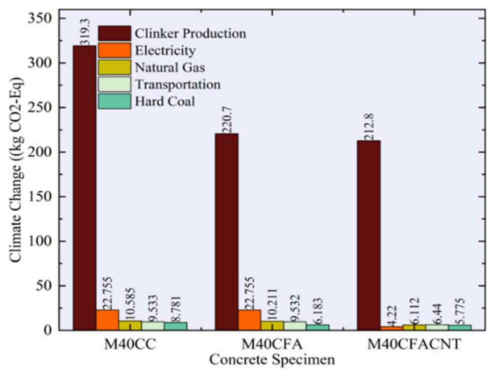

Figure 3. Climate change impact contributors among different mixes

C. Energy Resources

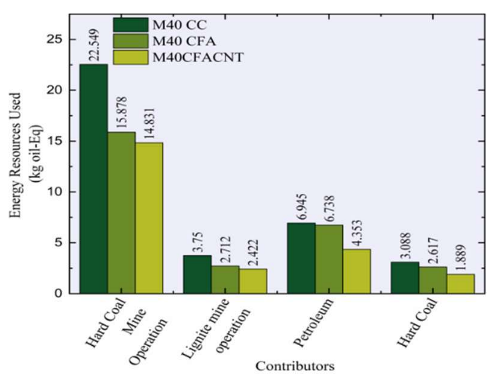

Figure 4. Non-renewable energy resource impact contributors among different mixes

In figure.4 the comparative analysis of non-renewable energy resource consumption across different concrete specimens M40CC, M40CFA, and M40CFACNT, the Environmental impact improvement using alternative materials for concrete results in Environmental benefits. In the case of M40CFA, the alone usage of fly ash reduces hard coal mine operations which uses energy resources reducing by 29.6%, lignite mine operations by 27.68%, and hard coal consumption by 15.25%. The addition of carbon nanotubes in M40CFACNT makes this further by achieving additional reductions of 34.2% in hard coal mine operation, 35.41% in lignite mining, 37.32% in petroleum, and 38.83% in hard coal. These benefits are because of the higher consumption of fly ash and CNT combining with lower clinker content. Overall, the findings demonstrate that combining secondary cementitious materials and nanomaterials to enhance the life of concrete and shifts toward less harmful environmental effects while conserving non-renewable energy resources.

D. Human Toxicity Carcinogenic

The human toxicity (carcinogenic) impact of different concrete specimens is shown in figure.5. M40CC, M40CFA and M40CFACNT is assessed in terms of emissions from various sources including electric arc furnace slag, hard coal ash, hard coal mining, lignite mining, and basic oxygen furnace slag. The contribution of arc furnace slag, the farthest-reaching contributor, drops from 13.52 units to 9.25 units, a reduction of 31.6% respectively. Adopting these changes aligns with healthier and more sustainable approaches.

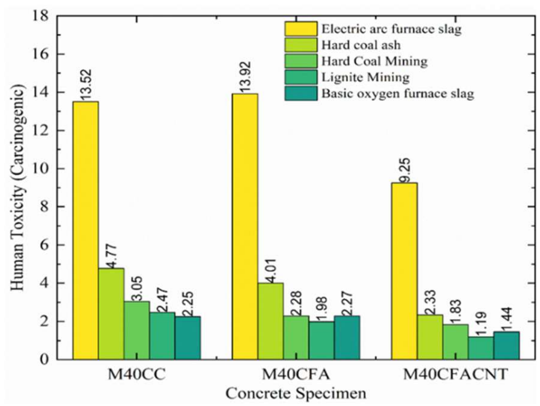

Figure 5. Human toxicity (carcinogenic) impact of different among different mixes

IV. CONCLUSIONS

Using OpenLCA and the Ecoinvent database LCA model of concrete mixes prepared with M40CC (OPC), M40CFA, and M40CFACNT, the conclusions are drawn.

- Using fly ash partially in place of OPC decreased reliance on natural resources while also lowering the carbon footprint and pollution emissions during conventional concrete use.
- As for 1 m3 of concrete, the mix made by OPC (M40CC) generates the highest environmental impacts in all categories. The M40CFA mix reduces by 18.73% the acidic potential, by 14.89% the use of non-renewable energy resources, by 5.69% the human toxicity (carcinogenic potential).
- The incorporation of carbon nanotube (CNT) along with fly ash in the M40CFACNT mix further amplified the environmental benefits. In comparison to the conventional M40CC mix, this mixture decreased the potential for acidification by 39.90%, the impact of climate change by 38.24%, the use of fossil fuels by 39.38%, human toxicity (carcinogenic) by 36.98%, human toxicity (non-carcinogenic) by 31.85%.
- Coal mining activities and electricity use also significantly increased environmental burdens, particularly in terms of energy use and toxicity-related effects. However, because of the reduced cement content and altered processing requirements, their impact was significantly diminished in the M40CFA and M40CFACNT mixes.

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