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Life Cycle Assessment on the Utilization of Waste Tires in Cement Production and as Partial Substitute for Fine Aggregates in Concrete

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Abstract— Natural Resources in this world are being consumed in a rapid pace especially in the application of Civil Engineering where most of the structures are made with cement and concrete. It is notable that within the production of those materials, emits many harmful emissions which will disturb human life and the ecosystem. This study intends to reduce the environmental impact of cement and concrete, by substituting waste tire to fossil fuels and substituting crumb rubber to fine aggregates. Previous research has proven the possibility of using these specific materials as partial substitute to its original processes. Life Cycle Assessment (LCA) of utilizing waste tires in the production of cement and concrete was assessed. SimaPro was utilized to quantify the environmental impact analyzing a one (1) kilogram of cement and one cubic meter of concrete. For the midpoint analysis of cement, it only showed a small difference but further analyzing it was discovered that substituting 30% waste tires to fossil fuel by weight will reduce the emissions of fossil fuel alone by 20%. The reduction of emissions of fine aggregates was directly proportional to the amount of substitution. In conclusion, the utilization of waste tires and crumb rubber did not cause any more harm to the environment and will also lessen the usage of natural resources.

Keywords*— Life Cycle Assessment, Rubber Tire, Waste Tires, SimaPro, Cement*

I. INTRODUCTION

The rapid growth of the population and the advancements made in transportation resulted to the increase in tire production for vehicles [1], consequently, waste tire rubber will also increase. Used tires are non-biodegradable waste that can cause environmental hazards. Land Filling of these waste tires produces harmful toxic gases that can negatively affect the environment and may cause devastating pollution to the natural air [2], [3], which leads up to the harmful effects that it will impose on human health. By recycling waste tires, it will not only be beneficial for human health and the environment as it will also preserve the natural resources. Natural Resources in this world are being consumed at a rapid pace [4], therefore utilizing waste products that can be applicable to concrete should be further studied. One alternative is using waste tires as substitute for aggregates in concrete. Multiple studies have shown decent effects of adding rubber to concrete, the compressive strength of the concrete may have decreased but it was stated that if the w/c ratio is decreased the compressive strength will improve. Decreasing the amount of natural fine aggregates in concrete by using waste rubber tires as partial substitution will lead to a reduction of harmful effects on the environment.

Another way of conserving natural resources in the industry is the use of alternative fuels for cement production. From the clinker production, 50% of the carbon dioxide emissions come from the burning of fossil fuels. The use of alternative fuels will not only conserve natural resources, but it will also reduce the emissions cement production releases because an approximate of 5%-7% of global carbon dioxide emissions and 3% of total greenhouse gasses comes from the production of cement [5]. Carbon dioxide emission is very alarming nowadays. People need to think some ways on how to reduce carbon dioxide emission due to high carbon emission in the whole world.

In the construction industry, aside from cement, aggregate type, mix design method and transport distance of raw materials also contribute altogether to the earth related issues [6]. To expand the natural awareness in the construction industry, assessment of the environmental exhibition of construction materials by Life Cycle Assessment (LCA) is hence required [7]. LCA is a method for assessing the product or services to its impact on the environment [8]. The whole idea of the LCA is analyzing a particular product or services done to its whole life [8]. It is not only from the extraction of raw materials, but it also includes the pre-manufacturing, manufacturing, its use and up to its end of life or disposal of the product [8]. In this study, SimaPro was used to perform Life Cycle Assessment.

II. Related Work

Suhirtha and Umamaheswari suggested for the reduction of the use of cement and sand, since there is a need to replace a part of cement by some pozzolanic material, to minimize and even control the environment pollution [9].
A study conducted by Farina [10] in which they performed a Life Cycle Assessment, using SimaPro, of different scenarios regarding construction and demolition waste (CDW). The scenarios that were proposed are where the CDW was completely landfilled and where the CDW was substituted for aggregates in concrete at different percentages. The scenarios also considered the differing distance to the construction site. It revealed that the most harmful result was showcased when the CDW were completely landfilled and concrete with 10% substitution of aggregates that were transported to a greater distance, thus, the best result was when concrete with complete substitution of aggregates revealed the ideal result although the study did not consider the mechanical properties of the concrete.

Farina et. al. [11] utilized SimaPro as a LCA tool, where they compared the environmental impacts of two types of green roofs, intensive and extensive, to the traditional roof. It was discovered that the impacts made by the materials used for green roofs are lower than the traditional roofs which specifies in the study that renovation and restoration for traditional roofs are more recurrent than green roofs resulting in a higher environmental burden. U. Hasan, A. Whyte, and H. Al Jassmi conducted a study wherein they performed a Life Cycle Assessment using SimaPro to determine and examine the environmental impacts of different alternate options for roadworks [12]. The alternate options are recycled construction waste, reclaimed asphalt pavement, and warm-mix asphalt. By using SimaPro, the researchers determined that using recycled construction waste as an alternate backfill material makes the global warming potential reduced by 16%. Another result was the use of warm-mix asphalt with added reclaimed asphalt pavement. By using this, the global warming potential and fossil fuel depletion were reduced by 59% and 70%, respectively.

III. Methodology

3.1. Data Gathering

The data and information needed in the Life Cycle Assessment were gathered from previous literatures and from cement manufacturers. The data gathered are sources of raw materials, equipment used, fuel and electrical consumption, water consumption and volume of produced cement and concrete.

3.2. Life Cycle Assessment

ReCiPe 2016 was used as the impact assessment method for both midpoint and endpoint analysis. For the inputs and outputs that would be selected in the system, the following categories were used to analyze using midpoint method: Global Warming, Ozone Depletion, Ionization Radiation, Ozone Formation, Fine Particulate Matter Formation, Terrestrial Acidification, Eutrophication, Eco toxicity, Human Toxicity, Land use and Water use. The following categories were also analyzed using endpoint analysis by quantifying the damage it would be contributing to human health and damage to the ecosystem.

Life Cycle Assessment on the utilization of waste tires for cement production and as partial replacement for aggregates was done using the SimaPro software. SimaPro is used to determine the impact in the substitution of fossil fuel to fine aggregates. The SimaPro included the summary of the results from both midpoint and endpoint analysis. For further analysis, multiple variations of fine aggregate replacement for crumb rubber up to 10% were done to quantify the differences in amount of the environmental impacts. SimaPro also indicated the largest benefactor from the system produced. All the processes mentioned were compared to its baseline process which is producing cement without any waste tire as alternative fuel and producing concrete without any substitution for fine aggregates to fully compare the results.

3.3. Life Cycle Inventory

The life cycle assessment includes the transportation of the raw materials. The raw materials were transported from the source to the batching plant for the concrete production. After the transportation phase, the environmental impact of the two processes was examined. The first process was executed by using waste tires as an alternative fuel replacing coal by 30% in cement production. The second process was the use of waste tire crumb rubber for 10% fine aggregate replacement in concrete, the second process also produced results for varying substitution to determine the difference in environmental impacts of different substitution rates. The other materials in producing concrete were the same. The mix design of concrete with fine aggregate substitution is shown in Table 1.

Table 1: Mix Design

Crumb Rubber (%)	Water (kg/m3)	Cement (kg/m3)	Crumb Rubber (kg/m3)	Sand (kg/m3)	Gravel (kg/m3)	w/c
0	189.69	373.38	0	609.60	1220.8	0.5
5	189.69	373.38	30.48	579.12	1220.8	0.5
10	189.69	373.38	60.96	548.64	1220.8	0.5

IV. Results and Discussion

4.1. Life Cycle Assessment - Midpoint

For global warming, considering fuel replacement the result has shown a decrease in emission, the production of cement without fuel replacement has shown a value of 0.91838696 kg CO_2. Substituting the fossil fuel by 30% using waste tires, decreased the emission by 0.033% resulting to a value of 0.91808434 kg CO_2. Further, the utilization of waste tires decreased the emissions from hard coals from the detailed results, the emissions emitted by hard coals decreased up to 20% which is from 1.59 x 10-3 to 1.22 x 10-3. It was also observed that clinker production greatly contributed to emission of this characterization factor.

In Concrete Production, from the simulation results, the production of cement without substitution of fine aggregates has generated a value of 401.23524 kg CO_2. Removing 10% of fine aggregates by weight and substituting crumb rubber it resulted to a value of 399.01102 kg CO_2 having a difference of 0.55%. The utilization of crumb rubber in the production of concrete only contributed 0.044990419 kg of CO_2 in the substitution and decreased the emissions omitted by the sand.

From the substitutions made, utilization of waste tires for cement production and crumb rubber decreased the emissions for global warming. For both cement and concrete the process that contributed mostly to the characterization factor is Clinker production contributing 99.3% and 86.52%, respectively. Varying the substitution of crumb rubber by 5% has shown a decrease of value for each substitution which is 0.278% for every 5%.

From the results, the original cement without any substitution released an amount of $1.79x10^{-5}$ CFC11 and decreasing the amount of coals by 30% has shown a difference of 0.56% in emissions resulting to $1.78x10^{-5}$. It is less impacting for to the ozone layer. Similarly, to the Global Warming, the activity which contributed greatly to this factor is the production of clinker out of the $1.79x10^{-5}$ clinker produced $1.63x10^{-5}$ which is 91.1% of the total emissions. Hard coals' contribution to the emission is $5.68x10^{-9}$ CFC11 decreasing its utilization by weight, resulted to a value of $4.55x10^{-9}$ which shown a difference of 19.89%. The counterpart used for coals, in its substitution only contributed to the emissions by less than 0.01%.

For the Stratospheric Ozone Depletion in utilizing crumb rubber in concrete, the difference between the changed mix designs has decreased by 0.82% from the original mix and 10% substitution mix. Observing the impact made by sand from the original mix, it contributed 15.6% of the total discharge of emissions, substituting the amount of sand by 10% has decreased its participation in the discharge of emissions which is only 14.2% of total emissions. It can also be observed that in the utilization of crumb rubber of 10% by weight has only contributed to the total emissions $3.02x10^{-4}$% which is satisfactory since its contribution is very minimal.

Considering the varying substitution, it is noticed that substituting 5% to the original mix design has a difference of 0.81%, and substituting 10% has shown a difference of 0.82% from the latter. The substitution for both cement and concrete has lessened the impacts that can be made of the characterization factor.

For ionization radiation, the cement production with no substitution has shown the greater value between the two which is 0.021232621 kBq Co- 60 and 0.02122194 kBq Co-60, respectively, the two has shown very minimal difference which is 0.05%. In the original production, the largest contributor to the emissions is the production of clinker which emitted 90.3% of the total emissions. Looking at the contribution of coals in the production of cement without any substitution it only emitted a minimal value of $5.50x10^{-5}$, but in the addition of waste tires, the emissions made by the coals has decreased to $4.40x10^{-5}$ having a difference of 20%, while the emissions made by the addition of waste tire 30% by weight it only contributed $3.22x10^{-7}$ it is mostly from the transportation of the material tothe cement manufacturing plant.

For the substitution of Fine Aggregates in concrete, the concrete without any modification has shown the greatest emission which is 13.55 kBq Co-60 substituting 10% of Sand in the mix design has decreased the emissions by 2.1% with a value of 13.27 kBq Co-60 with its largest contributing factor is cement which takes up 59.93% of the total emissions. For this characterization factor, the second leading contributor is sand which is 20.89% emitting 2.83 kBq Co-60, further observing this raw material, with the substitution of crumb rubber by 10% the difference between the emissions is 10.4% lessening its emission to 2.54 kBq Co-60, comparing its difference to the addition of crumb rubber, crumb rubber emitted only 0.004234993 kBq Co-60 which is 0.17% of the total emissions.

As regards to the ozone formation affecting human health, it was observed that the original cement production processes have resulted to a higher emission having a value of 0.00284202 kg NOx with its largest contributor, clinker, which is taking up 98.68% of the total emissions. Substituting 30% of coals with waste tires it has a decrease in emissions by 0.128%, for this characterization factor the results have been very minimal, but closely observing the effect of hard coals with and without the waste tire substitution it has shown a large decrease which is from $1.84x10^{-5}$ to $1.47x10^{-5}$, respectively. The change in the usage of hard coals by 30% has decreased the emissions made by the hard coals by 20.11%. The utilization of waste tires as a fossil fuel has contributed $1.85x10^{-8}$ which is less than 1% of total emissions.

In terms of fine particulate matter formation, the usage of waste tires in cement production has decreased the emissions of Particulate Matter, from 0.00145841 kg PM2.5 to 0.001457566 kg PM2.5. The substitution done by 30% has given a difference of 0.06%, which is very minimal but focusing on the effects done by the material in question, hard coals it has emitted $4.25x10^{-6}$ kg PM2.5, and by changing 30% of hard coals required for the production of cement it has reduced to $3.40x10^{-6}$ reducing the emissions by 20%, the change in emissions between the two is notable. From the 0.001457566 kg PM2.5, the waste tire that has been substituted has only emitted 0.0004% of the total emissions for Particulate matter which is negligible due to its very minimal PM2.5 emissions.

In terms of terrestrial acidification, it was noted that the cement production without the use of alternative fuels had a result of 0.00434428 kg SO2 while the cement production with partial substitution of fuels by using waste tires had a result of 0.004341506 kg SO2. Therefore, substituting the fossil fuel by 30% using waste tires decreased the emission by 0.064% compared to cement production without the use of alternative fuels. Separating the results of the effect of the hard coals, it resulted to a value of 1.39×10^{-5} for the traditional way of producing cement, this value may be minimal but the difference it made when utilizing waste tires was reduced to 1.11×10^{-5} which has shown a decrease of 20%.

For eutrophication, it is recorded that the cement production without the use of alternative fuels had a value of 0.000198532 kg P while the cement production with partial substitution of fuels by using waste tires had a value of 0.000185839 kg P. Thus, substituting the fuel by 30% using waste tires diminished the emission by 6.4% compared to cement production without the use of alternative fuels, comparing this result to the other characterization factors, it has shown a great decrease due to the large effect of coals for this midpoint factor. Isolating the material in discussion, hard coal's contribution to the total emissions for the traditional way of making cement is 6.35×10^{-5} which is 3.2% of total emissions behind only clinker. The utilization of waste tire at 30% reduced the emissions by 20%, and only contributing less than 0.001% to total emissions.

For the Terrestrial Ecotoxicity, the total emission produced in cement production without the use of alternative fuels had a result of 1.8759276 kg 1, 4-DCB and substituting the fossil fuel used to produce cement by 30% using waste tires decreased the emission by 0.049% resulting in a value of 1.8749924 kg 1,4-DCB. Like some of the other characterization factors this change is very minimal, but looking at the change in the emissions of coals at 0% substitution and 30% substitution it went from 0.005025416 kg 1, 4-DCB to 0.004020333 kg 1,4 –DCB, which has shown a substantial decrease of 20%, this decrease is very meaningful as adding the effect of waste tires 6.99×10^{-5} kg 1,4-DCB which at most did not add up to the emissions at 0% substitution.

For human carcinogenic toxicity, the production of cement without any fuel modifications produces a result of 1.0633056 kg 1,4- DCB while for the 30% fuel substitution of waste tires produces a value of 1.0137426 kg 1,4-DCB. As calculated, the value of fuel without substitution decreases by 4.67% by a 30% fuel substitution using waste tire. Furthermore, the process of clinker production contributes 71.8% which is the greatest contributor for cement production. Isolating the effect of hard coals in both situations, hard coals emitted an amount of 0.24784251 kg 1,4-DCB which then reduced to 0.19827401 kg t,4-DCB which resulted to a difference of which has 20%.

For the land, the cement production without fuel substitution produces a value of 0.15724863 m2a crop eq. substituting a 30% waste tire as fuel produces a decreasing of emission to 1.2% which generated a 0.15535662 m2a crop eq. For the highest contributor, clinker production generated a value of 0.14118974 m2a crop eq which is 90.88% from the whole emission.

For water consumption, it is recorded that the cement production without the use of alternative fuels had a value of 0.0047811963 m^3 while the cement production with partial substitution of fuels by using waste tires had a value of 0.0047794802m^3. Thus, substituting the fuel by 30% using waste tires diminished the emission by 0.0359% compared to cement production without the use of alternative fuels. Like the previous, characterization factor and the largest contributor is the clinker taking up 69.5% of total emissions. Hard coals for this midpoint result, only emitted 8.61×10^{-6} but considering the change in fuel it was reduced to 6.89×10^{-6}, reducing the amount by 19.9%.

4.2. Life Cycle Assessment - Endpoint

For human health, the cement production between the cement with 0% substitution and 30% substitutions, the latter had a more negative impact in the environment. The cement with no waste tires as alternative fuel resulted to an amount of 3.5×10^{-5} DALY and considering the amount of average cement made per month, 1,530,000,000 kg it will reduce the mortality of human by 53,550 years. Considering the 2.86% difference between the two, cement production with 30% of fuel are waste tires increased the mortality of humans by reducing it to 52,020 years, the difference between the two has a drastic change since it has a difference of1,530 years.

Global Warming, Ionization Radiation and Fine Particulate Formation has shown the greatest influence for this characterization factor, because for both cement production it did not see any changes, this result is expected due to the midpoint results it created, it was barely felt, and it has shown in endpoint analysis. However, it did show a decrease in years taken by human life therefore, it has shown a positive result.

For concrete production, it has also shown a decrease in DALY as the substitution progresses. The mix design with 0% fine aggregate substitution has shown a value of 0.016219891 daily and considering the largest substitution it has decreased to 0.016079499 having a difference of 0.87%, this is expected because in the results from the midpoint characterization factors for concrete production, cement has the largest effect. Since the concrete batching plant produces 875 m3 of concrete monthly, the processes that concerns its production is 170.31 years and 168.83, respectively.

Table 2 shows that almost all the endpoint categories have shown a decrease, hence, the result for the endpoint of Human Health is considered a success since it did reduce the life that will be taken away from humans.

Table 2: Endpoint Results for Concrete Production per Category

Endpoint Category	0%	30%
Global warming, Terrestrial ecosystems	2.30E-08	2.30E-08
Global warming, Freshwater ecosystems	6.26E-13	6.26E-13
Ozone formation, Terrestrial ecosystems	3.69E-10	3.69E-10
Terrestrial acidification	9.21E-10	9.20E-10
Freshwater eutrophication	1.33E-10	1.24E-10
Marine eutrophication	2.14E-14	2.01E-14
Terrestrial ecotoxicity	2.14E-11	2.14E-11
Freshwater ecotoxicity	8.79E-12	8.55E-12
Marine ecotoxicity	1.03E-08	9.84E-09
Land use	1.40E-09	1.38E-09
Water consumption, Terrestrial ecosystem	1.10E-11	1.10E-11
Water consumption, Aquatic ecosystems	4.76E-16	4.75E-16

Table 3 presents the endpoint results for cement production. The global warming for three of its categories has produced a result the same as human health which has shown little to no difference, however, freshwater, and marine eutrophication has shown the largest decrease of 6.8% and 6.1%, respectively. The results are anticipated due to the results that came from the midpoint analysis, but it still shows a positive result since it decreased.

Table 3: Endpoint Results for Cement Production per Category

Endpoint Category	0%	5%	10%
Global warming, Human health	0.005015431	0.005001 5	0.0049876
Stratospheric ozone depletion	1.33E-07	1.32E-07	1.31E-07
Ionizing radiation	1.90E-07	1.88E-07	1.86E-07
Ozone formation, Human health	1.30E-06	1.29E-06	1.29E-06
Fine particulate matter formation	0.000400808	0.000399 7	0.0003986
Human carcinogenic toxicity	0.001665423	0.001658 3	0.0016511
Human non-carcinogenic toxicity	0.00913248	0.009084 5	0.0090365
Water consumption, Human health	4.13E-06	4.13E-06	4.12E-06

Out of all the midpoint categories for fossil fuel replacement, it was found out that substituting waste tire for fossil fuel greatly affected these characterization factors: Freshwater and Marine Eutrophication having a difference of 6.4% and 6.2%, respectively, Freshwater and Marine Ecotoxicity having a difference in emission of 2.77% and 4.04%, lastly, Human Carcinogenic and Non-carcinogenic toxicity with a change in emission of 4.67% and 4.14%, respectively. For Concrete, two out of the 16 midpoint factors have shown the most change in emission when it comes to concrete, where in Ionization Radiation decreased for 2.1% and Terrestrial Ecotoxicity changed at a percentage of 2.61%.

Considering the results of the midpoint category for fossil fuel replacement hard coals was networked into two main categories which is hard coal mine operations and transportation, the changes that occurred were all from the hard coal mine operations, while the emissions coming from the transportation showed no decrease as it remained constant. For fine aggregate replacement, under the network of sand there were two main subcategories which is excavation and transportation, considering all the characterization factors, both showed decreases in emissions, but excavation showed the larger decrease.

The substitution rates used for this simulation will not sacrifice the strength of concrete as the mechanical strength is all within the standards therefore it is a viable option as an alternative material. Based on the summary of results, the utilization of waste tires and crumb rubber for cement and concrete production showed a reduction in emission for all impact categories.

V. Conclusion and Future Scope

The results from the simulation for the midpoint categories has only shown a slight decrease in total emissions but if the raw materials in question are isolated, for coals it has shown a great decrease for all characterization factors for the midpoint analysis it showed an average of 20% decrease in emissions of the hard coals if 30% was substituted by waste tires. For the fine aggregate substitution and concentrating on the emissions made by sand, the emissions lost is directly proportional to the percentage of the sand. The material used for the substitution only contributed to less than 1 percent of total emissions therefore it showed a positive result.

The usage of waste tires is a viable option in the industry of cement and concrete as it preserves natural resources, and because of their huge sizes and hollow shapes, tires occupy a lot of room in landfills. Furthermore, tires are non-biodegradable, which means that it does not break down into their natural forms which can prompt natural concerns, like water and air contamination and obstruction of seepage systems. A diminished volume of tires on landfills will naturally decrease the problems, especially the harmful emissions that they produce from landfills.

Future researchers should focus more on the substitution of cement because in all the characterization factors it is heavily dominated by the emission made by the production of concrete. Since there are many alternative wastes that can be utilized in the industry, a life cycle assessment of comparing these different alternative materials should be made, so that the most environment-friendly material can be found.

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