REDUCING ENVIRONMENTAL EFFECTS AND ENHANCING DESIGN CAPABILITY OF ARCHITECTURAL STRUCTURES

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ABSTRACT

This article addresses the energy saving potential and environmental benefits of recycled polypropylene (PP) usage as a construction material. PP polymer is a versatile material that can be used as films or fibres which makes it one of the most four selling and consumed plastics. PP usage accounts for 75% of the worldwide usage of plastics in the world, this plastic material accumulates day by day in landfill damaging the ecosystem and environment enormously for the last decades. The objective of this study is to reduce waste, find a greater resource productivity, and help decrease the environmental impacts of construction materials manufacturing, and consump-tion (convert Waste to Wealth). In this study, two samples having the same volume ($1m^3$) of self-compacting concrete (SCC); (one consists of PP fibre while the other one doesn't) have been compared in accordance with their Life Cycle Assessment *(LCA)* by using GaBi software. The emission to air and emission to fresh water for SCC reinforced concrete and PP reinforced concrete are calculated to be $4.53x10^5$, $5.66x10^6$; and $2.51x10^5$, $2.78x10^5$ respectively for 100 years of life cycle. The results showed that, for a 100 years of life cycle, the emissions to air and fresh water should be decreased by 44.59% and 91.99% respectively. The biggest benefit was mitigating the area occupied by plastic waste in landfill in bulky quantities, and also preventing lead disposal happening due to disposal of the PP based materials.

Keywords*:* Polypropylene (PP), Recycling, Enhancing design capability, GaBi, Life Cycle Assessment (LCA).

1. INTRODUCTION

1.1. Life Cycle Assessment

The rising environmental awareness inspires towards fulfilling the environmental norms. **Life Cycle Assessment** is a methodology to estimate the environmental effects of a product/plan or action methodically during its entire life, from extraction of resource, use, exclusion. All of those phases are the Life Cycle of a product. Life cycle assessment has different types of system boundaries, but the type used in this study is **Cradle to Gate** life cycle assessment system boundary, which contains all processes from the raw material to the production stage (gate of the factory).

1.2. Sustainable Concept in Manufacturing

For manufacturing decision makers, the economic aspect of sustainability in the past was the only addressed dimension of sustainability. Lately, companies have been more concentrated on environmental sustainability apparatuses, and concepts such as carbon footprint estimating, life cycle assessment [31]. There are many studies related to LCA of buildings in the literature [5-8].

1.3. Problem statement

According to [17], in the 1950's Ziegler and Natta's had used an anionic coordination catalyst by which PP and other stereospecific polymers were invented. Ziegler mechanisms, had produced commercially available PP via free radial addition polymerization. PP became the most widely used polymer in the world, therefore most detergent bottles, all bottle caps, packaging, and other uses PP had been manufactured for. As a result, accumulation of PP plastic wastes in bulky quantities has been witnessed, and the perception of running out of the landfill space started to be taken into consideration, and further that plastics are a problem specifically because their nature is non-biodegradable that cannot be dissolved, were seizing the limited landfill area available for what seemed an eternity, is a very big problem on the environmental level.

2. MATERIALS

2.1. Polypropylene (PP)

Using recycled PP fibre in concrete mixtures were studied in many articles since this type of recycling was developed in the last decades. However, studying LCA of a sample of PP fibre reinforced concrete and comparing it with a sample of SCC has a limited similar case studies which makes reference related to this study listed down in this chapter limited.

According to [11]; [14], and many other researches PP has been invented since 1950's by Ziegler and Natta's. They had worked on anionic coordination catalysts led to the inventing PP. The morphology of concrete containing PP materials is described in this paper to explain the influence of PP fibre on the properties of concrete [15]. Aspect ratio in general used to mainly describe any fibre, and it's the ratio of length of the fibre to its diameter. Generally, it shouldn't exceed 75 in value

2.2. PP Characteristics

2.2.1 PP Carbonation Depth

Carbonation is a common degradation of concrete. Increasing PP fibre volume fraction in the concrete composite, increases the carbonation resistance uniformly. The carbonation resistance of concrete composite can be measured by carbonation depth of specimen under the action of CO2 pressure, process is to diffuse CO2 from the surface to inside of the specimen. The carbonation depth increases, as the diffusion depth of CO2 increases [37]. Another study advocated the fact that PP increases the carbonation resistance stating that PP fibres let the capillary channels in the mortar blocked and minimize capillary pores. Furthermore, PP fibres reduce micro cracks in concrete which reduce in turn diffusion channels of CO2 enhancing the carbonation resistance eventually [33].

2.2.2 Workability

The workability of concrete mixture contains fly ash and silica fume is inversely proportional to PP fibre volume fraction in the mixture [37]. In the same research they proved the same conclusion on concrete mixture without fly ash and silica fume, and that adding PP fibre has significantly increased the durability of the concrete mixture that consists of fly ash and silica fume. Figure 1. shows the effect of PP fibre volume fraction on slump test of concrete mixture which contains silica fume and fly ash [37].

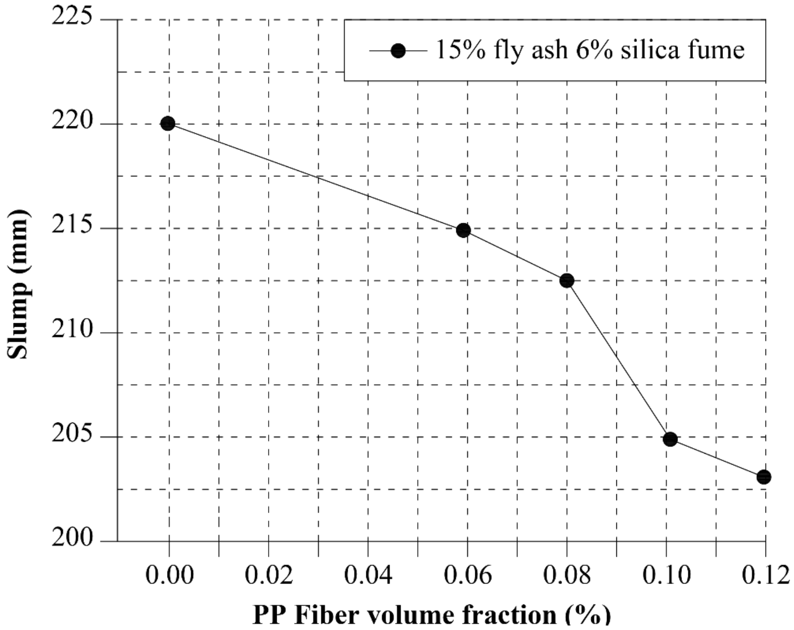
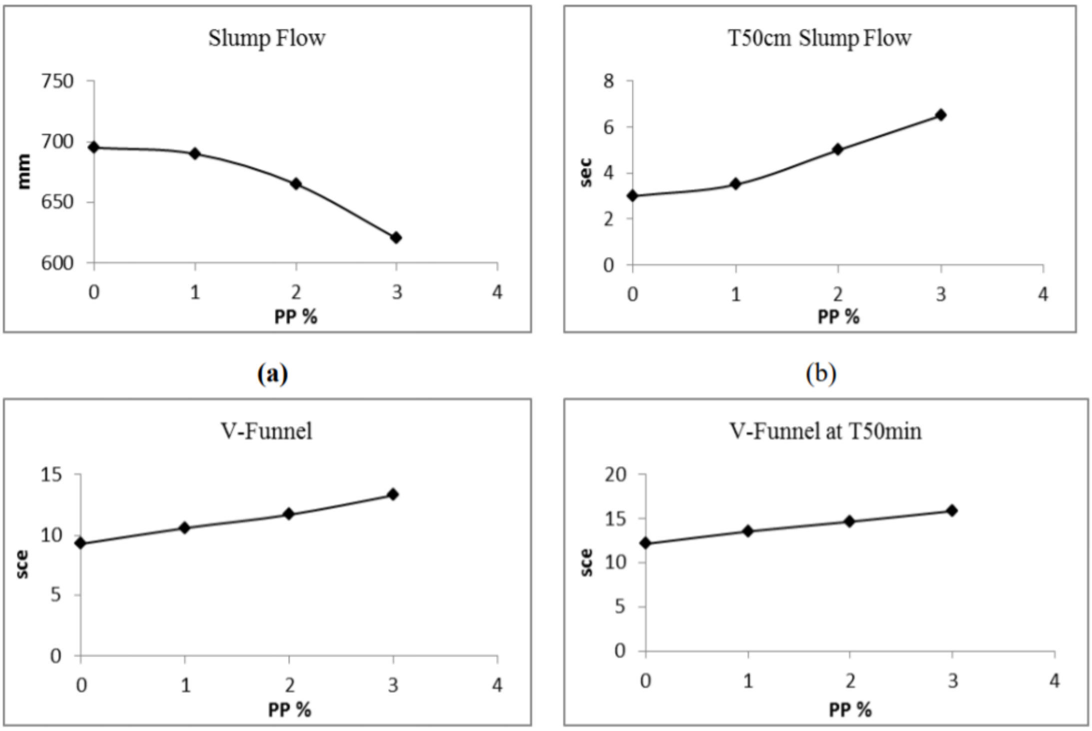


Figure 1. The Effect of PP Fibre Volume Fraction on Slump

According to [30] for 2 % percentage of PP, this is the influence of using PP on the workabilty as shown in Figure 2.



(c) (d)

Figure 1. Effect of PP Fibre on Flowability of the Fresh SCC [30]

It was proved that blocking effect by PP, and steel fibres decreases the serious segregation in lightweight concrete [25]. It had been observed that adding fibres particularly steel and PP fibre to concrete composite resulted in decreasing the sedimentation of aggregates, and the surface bleeding. Moreover, improved the homogeneity in light weight concrete (LWC) [12].

2.2.3 Compressive strength

The compressive strength of concrete is enhanced proportionally by adding up to 2.0 % of PP fibre by cement volume, and then tends to decrease on 3.0 % of addition [30]. In other studies, it was witnessed that PP has an adverse impact on the compressive strength of the concrete to about 1 to 10% [24]. When the concrete contains silica fume and fly ash with PP fibre all together can make a substantial effect increasing in strength up to 23% [2]. It was also observed that the loss in weight and gain in compressive strength of the cubic specimens enhanced with age. In this study fly ash was added by dosage of 2.4%, PP was also added to the concrete mixture by dosage of 2% to gain the optimum properties

that might be obtained by setting the best proportional averages according to these previous studies.

2.2.4 Flexural strength

Some increasing in flexural strength was achieved by adding 0.4% PP fibre [25].

2.2.5 Tensile strength

It was observed that both steel and PP fibre together can enhance the tensile strength of light weight aggregate (LWA) concrete up to 116% [25]; [37].

2.2.6 Shrinkage Test

Increase in PP fibre volume fraction up to 0.12%, decreased in 90 days ultimate dry shrinkage strain [37]. Also, it was observed that high volume fly ash concrete reinforced with PP fibres, achieved decrease in drying shrinkage [26].

2.2.7 Impact Resistance

PP fibre enhance impact resistance of concrete, impact resistance increased up to 171% by adding of 0.2% fibre volume fraction [2]. It was studied numerically and experimentally that containing PP fibre enhanced the concrete impact resistance [1]

2.2.8 Permeability

A specimen of reinforced concrete includes fly ash and silica fume was studied by [37]. They observed that adding PP fibre reduced permeability. Furthermore, they observed that when fibre volume fraction was increased permeability of mix was decreased. It was also invested that the permeability was reduced noticeably with increase in fibre content and escalating curing age. The change in aspect ratio does not have a considerable effect on the water permeability of steel fibre reinforced concrete [35]. Table 1. illustrates the permeation of water and oxygen through different plastic materials [36].

Table 1. Barrier Properties of the Most Commercially Available Plastics [36]

Polymer	Permeability of oxygen at 25˚, 65% RH (cc,mil/100 in²/24 h)	Permeability of water at 40˚, 90% RH (cc,mil/100 in²/24 h)
Ethylene vinyl alcohol	0.05-0.18	1.4-5.4
Nitrile barrier resin	0.80	5.0
High barrier PVDC	0.15	0.1
Good barrier PVDC	0.90	0.2
Moderate barrier PVDC	5.0	0.2
Oriented PET	2.60	1.2
Oriented nylon	2.10	10.2
Low density polyethylene	420	1.0-1.5
High density polyethylene	150	0.3-0.4
PP	150	0.69
Rigid PVC	5-20	0.9-5.1

2.2.9 Fire Resistance

Adding PP fibres into the concrete mixture lessened the effects of elevated temperature on PP fibre reinforced concrete by minimizing crack growth in the concrete [21]. Table 2. shows mechanical characteristics (elastic modulus, tensile strength, ultimate elongation) of different fibre [34]. A study observed PP characteristics changes due to blending recycled PP with chloroprene rubber. This blending decreased the elastic modulus, and the tensile strength, but increased the ultimate elongation. This study also proved that PP and chloroprene rubber weren't compatible [18].

2.2.10 Spalling Resistance

Spalling is the damage that forces concrete surface to peel, or pop out laterally with explosions at a high temperature [32]. PP fibres were used to assess the spalling resistance of SCC. PP fibres are known to be spalling resistance factors. [3] had studied spalling of SCC with and without PP fibres exposed to elevated temperatures. During the study, it was witnessed that spalling happened in specimens that did not consists of PP fibre in the concrete mixture over 400 C˚. Furthermore, spalling did not happen in specimens that contain PP fibres over 0.05 % by volume, and spalling resistance behavior was notably enhanced. The presence of water inside the concrete, and the low permeability of the SCC are the main reasons for the spalling phenomenon. Water evaporates inside of the concrete, and vapor get retained producing high internal stresses which causes spalling. Whereas the morphology of PP which let it seize the capillary pores, and channels avoiding the previous condition of the vapor getting retained which protects the concrete from explosion and spalling phenomenon.

Table 2. Mechanical Characteristics of Different Fibres [34]

Fibre type	Elastic modulus MPa	Tensile strength MPa	Ultimate elongation mm
SCC	200000	500-2000	0.5-3.5
Glass	70000-80000	2000-4000	2-3.5
PP	5000-7000	500-750	8
Nylon	4000	900	13-15
Carbon	230000	2600	1

Table 3. Physical Properties of PP Fibre [37].

Density (kg/m^3)	Fibre length (mm)	Tensile strength (MPa)	Elastic modulus (MPa)	Melting point (˚C)

910	10–20	450	4100	160–170

PP Since had first been invented in the Fifties until the meantime, it had been also ranked and been compared with other polymer resins according to different experiments, and economic advantages. Table 4. illustrates the ranking of top 4 plastics for all the properties having significance. If the resin had been ranked for all significant properties, the scores are totaled for each material. The one with the highest total rank would then be the first choice [36]. WF here is an abbreviation for Weighing Factor (WF) as a multiplier assigned (according to the study) to reflect how much is that property is important. For example, stiffness might be given a WF of 10, which is the highest weighing factor because the stiffness is the most important property. All of the stiffness ranks might be multiplied with this WF to have the stiffness mark for each resin. PP is superior stiff, and its low price have resulted in its use in some structural applications. If there was a need for additional stiffness or strength, adding reinforcements to PP may increase its stiffness. For example, adding 30 % of short fibreglass can double the impact resistance and tensile strength of PP. Impact strength can also be improved by adding impact modifiers [36].

Table 4. Methodology for Ranking and Scoring Resin According to the Importance of the Properties [36]

Resin	Significant Properties						
	Stiffness		Solvent Resistance		Low Cost		Score
	Rank Score WF=10		Rank Score WF=7		Rank Score WF=7		Total
PE	1	10	4	28	4	12	50
PP	2	20	3	21	3	9	50
PS	4	40	1	7	2	6	53
NYLON	3	30	2	14	1	3	47

2.3 Properties of PP Reinforced Concrete

PP fibre reinforced concrete had found increasing applications in various elements such as: floors of factories, building walls and slabs, overlays. These applications are being encouraged by the enhancements in cracking properties, ductility, impact resistance, fire resistance, carbonation resistance, permeability, decreasing shrinkage strain, increasing tensile and flexure strength, enhancing durability. Volume fraction of PP fibre in concrete generally ranges from 0.05 % to 0.5 %. At these relatively low volumes, no additional precautions are needed for mix proportioning and manufacturing technique due to the presence of fibre, but if fly ash is also added so this ratio can go up to 2%. [10] assessed the PP reinforced concrete properties according to different volume fractions of PP fibre and it had been in the mixture of concrete shedding the light on the best volume fraction to be used. During the study they experimented variable fibre length and volume fraction taking them into consideration, invested slump test, air content, compressive stress-strain, flexural load-deflection relationship, permeability, rapid chloride, and then evaluated the volume percentage of permeable voids. Post-peak-based method of characterizing flexural behavior of PP fibre reinforced concrete performance had been reported. Figure 3. shows flexural load-deflection behavior of PP fibre reinforced concrete [10].

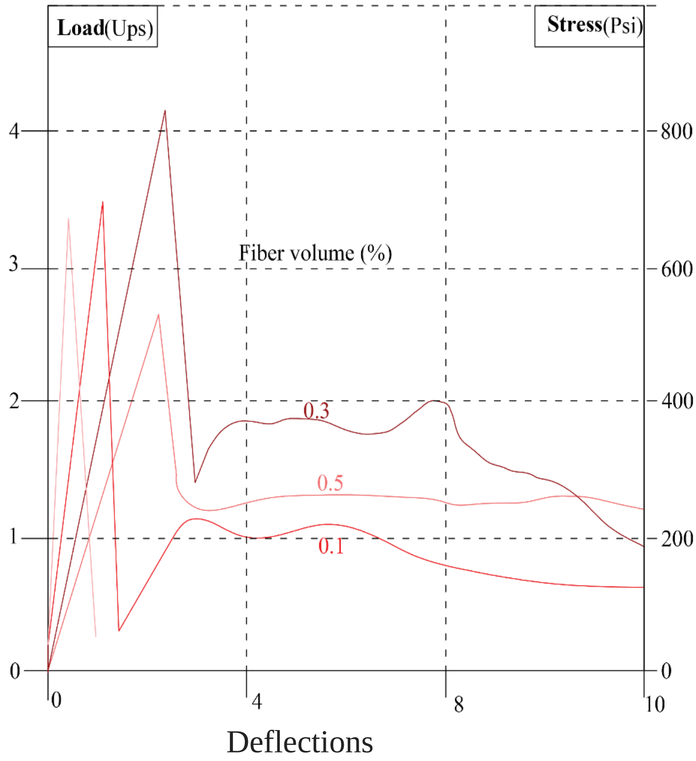


Figure 2. Flexural Load-Deflection Behavior of PP Fibre Reinforced Concrete [10]

Materials used in the experimental program of this research paper included: 1) Type 1 portland cement; 2) tap water; 3) natural river sand; 4) natural river pea gravel with a maximum size of 3/8 in. (9 mm); 5) collated fibrillated PP fibres with a specific gravity of 0.91, a tensile strength of 80 to 110 Psi (550 to 760 MPa), a modulus of elasticity of 500 Psi (3500 MPa), and a melting point of 160 C;6 and 6) a naphthalene form aldehyde sulfonate-based superplasticizer. Seven mixtures of PP fibre reinforced concrete were included in the experimental program of this research investigation. In these mixes: 1) cement content was (424 kg/m²); 2) water-cement ratio was 0.41; 3) aggregate-cement ratio was 4.0, which yields a dry aggregate content of (1696 kg/m²). Aggregates were considered to be at their saturated surface-dry condition in mix design. Fifty percent of the aggregates consisted of sand and the other 50 percent was gravel; 4) superplasticizer-cement ratio was 0.01; and 5) fibre lengths, volume fractions were as shown in Table 5. Two different fibre lengths and three different fibre volume fractions were considered. A reference mix which didn't contain fibre was also implemented [10].

Table 5. PP Fibre Lengths and Volume Fraction.

Mix number	Fibre length in fraction	Fibre volume fraction, Percent%
1	-	0
2	1/2	0.1

3	1/2	0.3
4	1/2	0.5
5	3/4	0.1
6	3/4	0.3
7	3/4	0.5

Workability Fresh Mix Test results are listed in Table 6 For fibre volume fractions less than or equal to 0.3 percent, fibre effect on fresh mix workability seems insignificant and rather inconsistent. For fibre volume of 0.5 percent, however, fibres seem to adversely affect fresh mix workability, as evidenced by the increase in inverted slump cone time with (19~mm) fibres with a more pronounced effect than in (13~mm) fibres. Similar conclusions can be derived from Table 6 regarding air content test results.

Table 1. Workability Fresh Mix Test Results.

Mix number	Slump, in mm	Inverted slump cone	Fibre volume fraction, percent
1	8.5	-	0
2	1/2		0.1
3	1/2	Inconsistent	0.3
4	1/2	18	0.5
5	3/4		0.1
6	3/4	Inconsistent	0.3
7	3/4	14	0.5

Compressive stress-strain relationships of PP fibre reinforced concrete are shown in Fig 2.6. Compressive behavior characteristics are listed in Table 7 Each compression test result in Table 7 is an average of two identical specimens. Table 7 includes compressive strength strain at peak stress and compressive toughness index. Compressive toughness index is defined as the total compressive energy absorbed (total area under compressive stress-strain curve).

Table 2. Compressive Behaviour Characteristics

Mix Number	Compressive Strength, MPa	Strain at Peak MPa
1	5700	0.0016
2	6550	0.0017
3	6800	0.0019
4	5560	0.0022
5	5400	0.0017
6	5800	0.0021
7	5600	0.0017

Figure 4 shows the changes concluding from changing PP fibre volume fractions on the shrinkage. [37]. **4-Carboration:** by increasing PP fibre content from 0% to 0.12%, carbonation decreases 37% from 2.4% to 1.5%. **5-Freeze-Thaw resistance:** in the concrete includes PP fibres is slightly exceeds the freezing-thaw resistance in the concrete which doesn't .Table 8,9. shows the mix proportions of the concrete mixture [37].

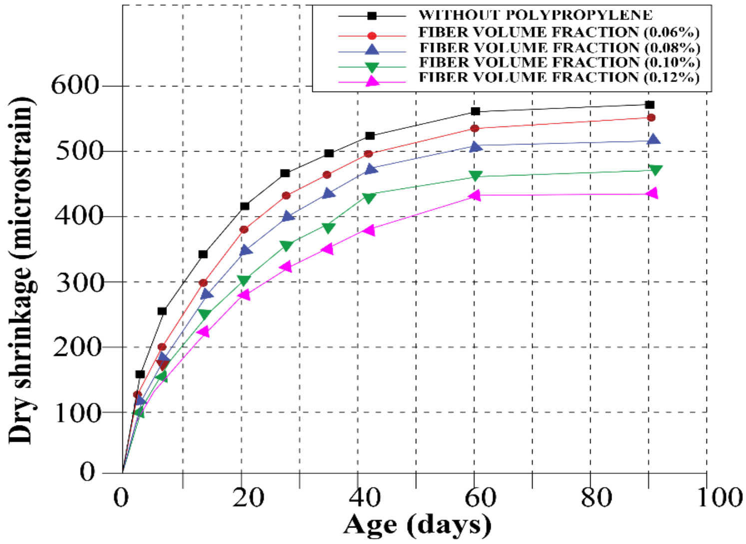


Figure 3. The Changes Concluding from Changing PP Fibre Volume Fractions on the Shrinkage [37]

Table 3. The Mix Proportions of the Fibre Concrete Mixture [37].

Mix no.	Cement (Kg/m³)	Fly ash (%)	Fly ash (Kg/m³)	Silica fume (%)	Silica fume (Kg/m³)	Fiber volume fraction (%)	Fine aggregate (Kg/m³)	Coarse aggregate (Kg/m³)	Water (Kg/m³)	Water reducer Agent (Kg/m³)
1	390.3	15	74.1	6	29.6	-	647	1151	158	4.94
2	390.3	15	74.1	6	29.6	0.06	647	1151	158	4.94
3	390.3	15	74.1	6	29.6	0.08	647	1151	158	4.94
4	390.3	15	74.1	6	29.6	0.10	647	1151	158	4.94
5	390.3	15	74.1	6	29.6	0.12	647	1151	158	4.94

Table 4. Mix Design with Addition of PP Fibres of on SCC [30].

Concrete Mix	Water (Kg/m³)	Cement (Kg/m³)	Fiber (Kg/m³)	Fine aggregate (Kg/m³)	Coarse aggregate (Kg/m³)	Super Plasticizer (%)	VMA (%)	W/C

SCC1(N)	165	408	0	790	675	7.33	7.33	0.44
SCC2 (1% F)	165	408	4.08	790	675	7.33	7.33	0.44
SCC3 (2% F)	165	408	8.16	790	675	7.33	7.33	0.44
SCC4 (3% F)	165	408	12.24	790	675	7.33	7.33	0.44

3. METHODOLOGY

This chapter represents all GaBi Program entries used to analyze the LCA of two specimens, the first is PP fibre reinforced self-compacting concrete the second is a SCC without PP addition. Each specimen is 1m³ volume. Each proportion was determined by a certain reference, rules and standards to achieve transparency in making comparison between the negative outputs of each specimen that might affect the environment, according to the standards of the American Society of Testing and Materials (ASTM). The PP have been chosen to get recycled which is considered effective and useful because of its availability in large quantities in the landfill as an ever-growing burden that doesn't seem to get solved. Thus, the conception of converting Waste to Wealth must be taken into consideration. Assessing the theory that took off a substance from the landfill (PP), used it in a useful way (especially the fact that this material has a great property that had been proofed through many researches), would be a great benefit to environment. This assessing procedure is called LCA of the product and the method used to achieve this study is GaBi Program.

3.1 GaBi Overview

GaBi is a holistic LCA tool, it can automatically track all processes. Material, energy, and emissions flows, also a custom processes and flows can be added. Eventually the program assesses the impacts of any product/plan on the environment. Figure 3.1 shows an overview of LCA.

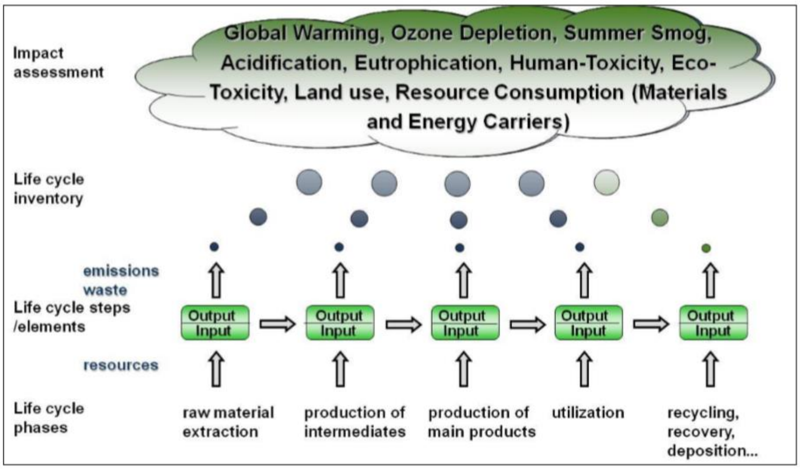


Figure 4. Overview of LCA

In Figure 6,7. Steps of a LCA according to ISO 14044 are shown, which are: 1. Goal and Scope Definition-2. Inventory Analysis-3. Impact Assessment-4. Interpretation.

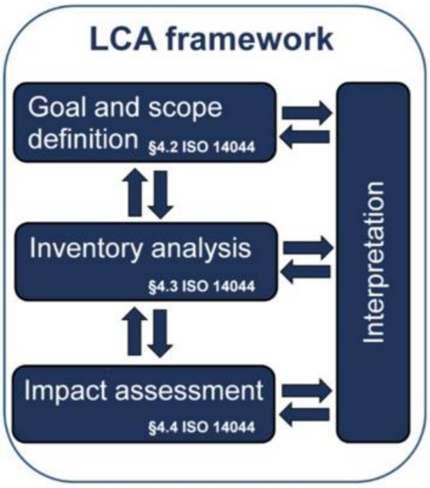


Figure 5. Steps of a LCA According to ISO 14044

3.2 Defining System Boundaries in GaBi

As mentioned in the first chapter in this study there are four types of system boundaries in life cycle assessment: **1-Cradle to Grave 2- Cradle to Gate 3-Gate to Grave 4-Gate to Gate**, so according to GaBi software, the system boundary must be selected in order to define the right impact of the product/plan during also a specific period of time. In this study (Cradle to Gate) type had been selected to shed the light on the recycling, and producing PP fibre reinforced concrete, and think about it as a sustainable alternative construction material.

3.3 Data Collection – Classifications

This phase is the most work intensive and time consuming of all the phases in an LCA. It includes collecting quantitative and qualitative data for every unit process in the system. The data for each unit process can be classified as follows. Figure 7. shows an example of data collection sheet.

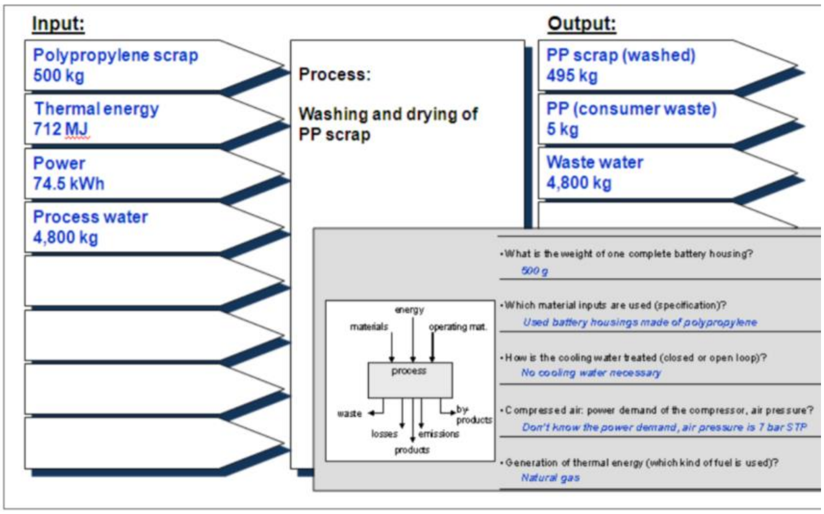


Figure 6. Example Data Collection Sheet

4. RESULTS AND DISCUSSIONS

The results of Gabi program output diagrams for both (PP fibre reinforced Concrete on the left and SCC on the right) for GWP (Global Warming Potential): The earth's surface partly absorption for the short waves occurring radiation occurring from the sun (leading to direct warming) and partly diffused as infrared radiation have been presented in Fig. 8. The reflected part of these waves is absorbed by greenhouse gases in the troposphere and then, it is reradiated in all directions, involving back to earth. A warming effect at the earth's surface concludes as a result [33] .

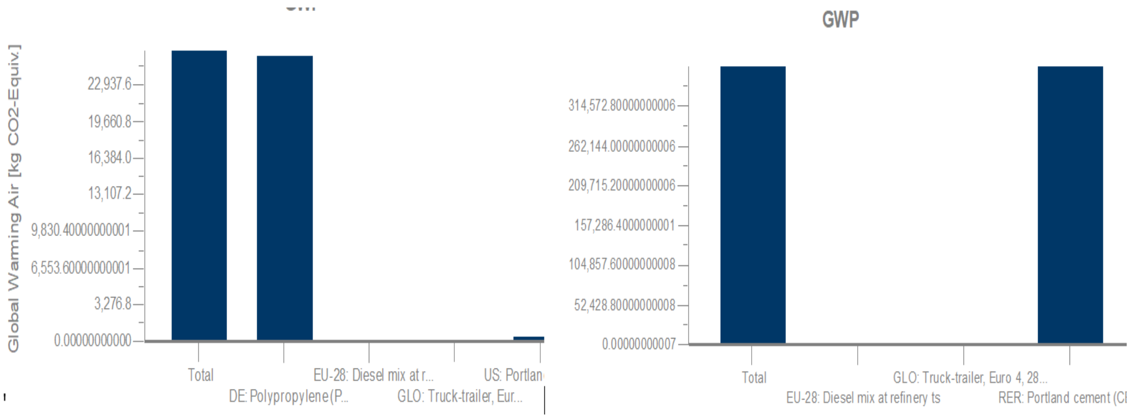
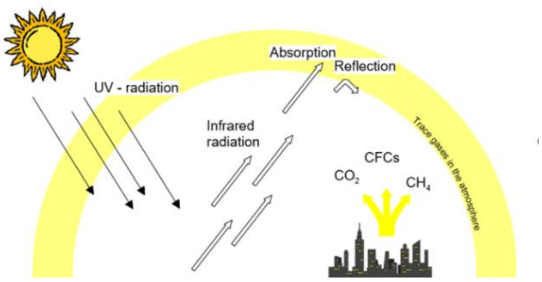


Figure 8. Global Warming Potential for pp Specimen on the Left and SCC Specimen on the Right.

Figure 9. shows the focal processes of the anthropogenic greenhouse effect.



Global Warming Potential (ISO 14044:2006)

Figure 9. Global Warming Potential Abstract (ISO 14044:2006)

In Figure 10 the results of Gabi program output diagrams for both (PP fibre reinforced Concrete on the left and SCC reinforced concrete on the right) for AP (Acidification Potential) which happens when the pollutants of the water and soil transform into acids This causes a reduction of the pH-value of rainwater and fog from 5.6 to 4 and below. Sulphur dioxide and nitrogen oxide and their respective acids (H2SO4 und HNO3) produce related contributions which damages forests mainly.

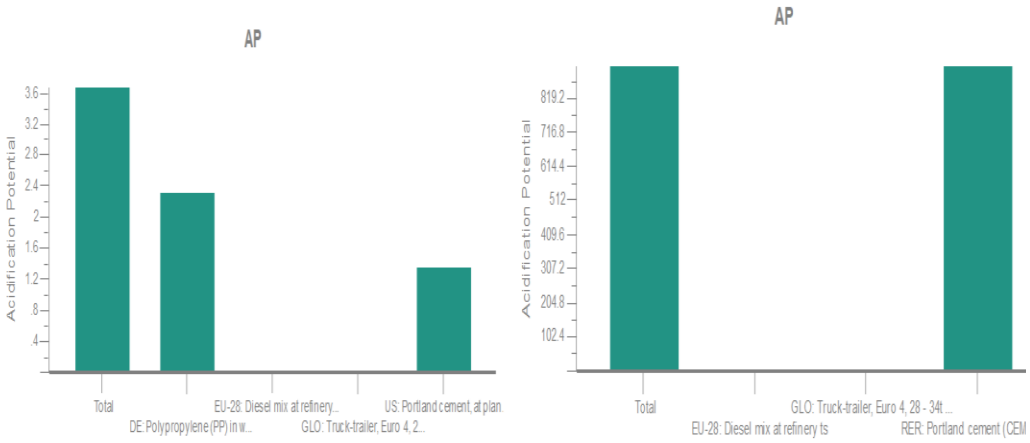


Figure 10. Acidification Potential for PP Specimen on the Left and SCC Specimen on the Right

Figure 11 shows the most important pathways of the impact of AP Acidification Potential (ISO 14044:2006).

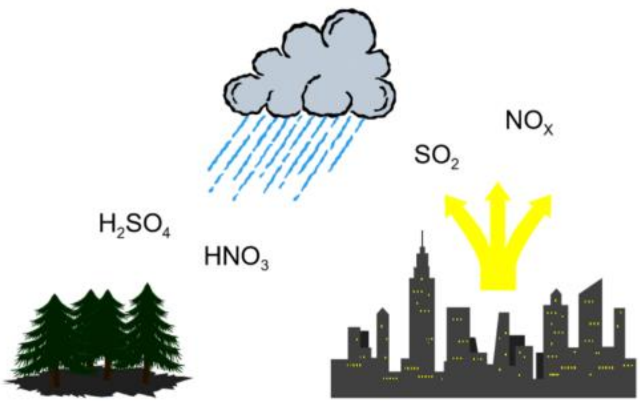


Figure 11. Acidification Potential Abstract (ISO 14044:2006)

5. CONCLUSION

5.1 Conclusion

This chapter presents the summary of the experimental works and an attempt to conclude the major the advantages and disadvantages of recycling the PP from waste convert it into PP film, the next phase is to manufacture the PP film transforming it into fibre. The addition of the PP fibre to the concrete mixture making the PP fibre reinforced concrete. These methods will save the construction costs as well as reduce the environmental and human health risks.
The results showed that, for a 100 years of life cycle, the emissions to air, fresh water should be decreased by 44.59% and 91.99% respectively.
Among the results the program provides there is **GWP, AP, EP**, **Ecotox Air, Human Health, Smog Air, Human Tox(cancer), ADP, GWP, TETP, ODP, Ecotox, Ecotox water, Lonising radiation, POCP, EP (**presented in Table 10).
Using PP fibre can enhance the detrimental characteristics of concrete like brittle be-havior, small durability, and low resistance to fatigue, that PP fibre let the capillary channels in the mortar blocked and minimize capillary pores. Moreover, PP fibre reduce micro and macro cracks in concrete which reduce in turn diffusion channels of CO_2 enhancing the carbonation

resistance eventually [30-38]. Many researches proved that PP can considerably enhance durability, impact resistance, toughness and tensile strength, of the cement matrix, preventing the growth, and crack opening in concrete. By adding PP to the concrete mixture especially with fly ash, and sometimes with both fly ash and silica fume which enhance its stiffness notably.

Table 10. Results According to GaBi.

The Results	PP fibre reinforced concrete	SCC
GWP (air incl CO_2) Kg CO_2	$2.6x10^{4}$	$3.67x10^{5}$
AP Kg SO_2	227	912
EP Kg Phosphate	0.204	102
Ecotox Air CTUE	1.2	$3.87x10^{3}$
Human Health kg PM2.5 eq	0.484	54.4
Smog Air	58.9	$1.82\ x10^{4}$
Human Tox(cancer) cases	$1.99\ x10^{-6}$	$8.8\ x10^{-5}$
ADP kg CFC 11 eq.	$4.29\ x10^{-4}$	0.0228
OZONE Depletion kg CFC-11 eq	$1.52\ x10^{-10}$	0.0179
TETP Kg DCB eq	0.789	423
ODP kg.R11eq	$1.52\ x10^{-10}$	0.0228
Eco tox CTUe	9.44	$6.3x10^{3}$
Ecotox water	6.41	$1.48x10^{3}$
Lonising radiation kbq	13.4	923
POCP kg Ethene	2.78	32
EP kg Phosphate	0.204	102
WATER kg	-113	3.2

5.2 Recommendations for Future Works

Further studies on the topic may illustrate the environmental effect of using different waste materials as construction materials. This thesis will be extended by investigating the life cycle cost (LCC) effect of PP in constructional and architectural applications.

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