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Corresponding author: m.medine77@yahoo.fr

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Life Cycle Assessment of Concrete Incorporating Scrap Tire Rubber: Comparative Study

Malika MEDINE[1], Habib TROUZINE[1], José Barroso DE AGUIAR[2], Hachemi DJADOUNI[1]

[1] *LGCE Civil Engineering and Environmental Laboratory, Sidi Bel Abbes University BP 89, Sidi Bel Abbes, DZ-22000, Algeria.*
[2] *Civil Engineering Department, School of Engineering, University of Minho, Guimarães. Portugal*

Abstract

At present, the environment suffers from two major problems, the first is the adverse effect of the production of the construction materials due to the resulting emissions and the second one is the increase of the consumption of the natural materials needed in the construction industry. There are interesting waste products such as the used tires that can be a resource of those materials to replace the natural resources in depletion. The use of scrap tire rubber to produce concrete in Algeria is not really an available technique. A life cycle assessment to compare an ordinary cement Portland concrete (*Cref*) and six rubberized concretes *(CRm)* and *(CRg)* from the environmental impact was carried out using ATHENA Estimator. The nine studied environmental impact categories are Climate change, Acidification potential, particulate matters, Eutrophication, Destruction of the stratospheric ozone layer, Photochemical ozone creation, Primary energy consumption, Consumption of fossil fuels, and Cumulative energy demand. The results inter-compared show that the energy demand and the generated emissions in the case of ordinary concrete are superiors than those of the rubberized concretes; concretes made with natural aggregates and 5, 7.5 and 10% of crumb rubber and coarse rubber aggregates *(CRm)* are more environmentally friendly than *(CRg)* mixtures made with natural aggregates and 5, 7.5 and 10% of coarse rubber aggregates. It is also concluded that the environmental impacts depend on the amount of substituted aggregates.

Keywords: Environmental assessment; Rubber aggregates; Concrete.

1. Introduction

The demand for raw materials is increasing due to human development and economic growth. After decades of production, concrete which consume a huge part of those materials is still the most used material in construction industry to date. Therefore, the question that arises is for when will the raw materials which are continually diminishing suffice?

It is not possible to determine the volume of natural resources or the duration in which they can be consumed without being exhausted since they are not renewable. Thus, the experts expect that the problem of imbalance between the demand of these materials and their volume in nature to worsen, so finding an alternative is necessary.

Many countries highlighted the vital need for new materials to support the construction's economy. As the number of available landfills continues to rapidly reduce, they established a clear relation cheap in between this problem and the demand for recovery of the non-degradable waste stream, to deal with sustainability, energy and environmental issues.

Furthermore, energy savings with recycling process is similar to crushed aggregate production and the energy demand will be similar for both processes. So, using waste in construction have called for greater debates about satisfaction of the conditions of resulting energy saving and the reduction of CO_2 emissions, to meet to the environmental requirements. It is generally agreed that current most often used construction materials as well as building methods are not durable, having large environmental impacts such as energies consumption, pollution, dusts, depletion of natural resources, generating considerable amount of solid waste and CO_2 emissions [1]. In concrete production the main responsible for CO_2 production is the use of ordinary Portland cement with a contribution rate roughly equivalent to 80-90% [2]. According to Letelier and al [3] cement industry is responsible of 5% of the CO_2 emissions worldwide.

Thormark [4] indicated that more attention should be accorded to the choice of materials. He adds that the use of dynamite which consists of sulfuric acid, nitric acid and sulfur substances favourites the emission of sulfur dioxide (SO_2). In the same meaning, Kumar [5] reported that extraction, processing and transportation of raw materials involve the consumption of large amounts of energy and generate environmentally damaging dust. Meddah [1] highlighted that increasing energy consumption from all sources could even contribute to the global climate change. He also revealed that reducing the global CO_2 emissions could be achieved by selecting materials that have lower environmental impact.

Many studies have been done to demonstrate the feasibility of using different wastes products as a partial substitute for natural aggregates in concrete applications. Among these abundant wastes; used tires which are produced excessively worldwide every year. According to Sofi [6] an estimated 1000 million tires reach the end of their useful lives every year and 5000 million more are expected to be discarded in a regular basis by the year 2030. According to Institute of Scrap Recycling Industries, 110 million tires are processed by recycling industry each year; 70 million tires are recycled into crumb rubber, playground surfaces, synthetic turf and more, 20 million tires are used for lightweight fill for road embankment, rail vibration dampening and other engineering uses. Algeria alone produces about 25.919 tons/year of used tires [7].

Used tires constitute an important amount of solid waste. These tires were often found dumped in bodies of water, in abandoned lots, and along roadsides, but today are recycled. Rubber has been recycled for about a century, but the market has greatly expanded in the past two decades due to an increased demand for scrap tires in a wide range of settings. Tire rubber has been used such as fine and coarse aggregates. The Institute of Scrap Recycling Industries, has noted that almost the studies have been conducted worldwide into crumb rubber conclude that there is no risk to human health. From an environmental point of view the acquisition of rubber aggregates can be considered healther when cutting is compared to extracting raw materials; its availability in future is not a concern.

The process of rubber granulation can be achieved through a wide range of recycling techniques. The mechanical processes are simple, consisting of cutting and compressing rubber with mechano-chemical treatments, while the thermal processes are extremely complex. This poses great challenges to the adoption of this recycling technology. However, with the increased costs of burying used tires, their use as aggregates in construction industry has become economically advantageous. The granulation of used tires, offers a better environmental impact as compared to the other ways of their reuse. The gains are mainly related to energy savings and avoided emissions [8].

Recycling saves impressive amounts of energy, which ultimately reduces greenhouse gas emissions; recycling four tires reduces CO_2 by about 146.5 kg which is equivalent to 68 L of gasoline. The transport of rubber aggregates does not significantly affect the environmental balance and generates almost no gas or particulate matter.

Recently, researchers have shown an increased interest in subject of life cycle assessment of the innovate products. Several studies have been carried out in the methodological framework of the life cycle analysis of waste recovered for the production of new cement materials, among these works we cite the work of Hadj Sadok [9]. We should note that no research has been found that investigated life cycle assessment of construction materials incorporating reused scrap tires. Most studies in this field have only focused on the study of use of scrap tires in cement plants and artificial turf.

Fiksel *et al.* [10] indicated a reduction in greenhouse gas emissions, air toxics, and water consumption. Every metric ton of tire-derived fuel substituted for coal in cement kilns avoids an estimated 543 kg CO_2 eq of direct and indirect emissions. Taking into account the deductible CO_2 from natural rubber, the avoided gas emissions would be 613 CO_2 kg eq per metric ton. In the field of rubberized concretes, there is no study based on the assessment of their environmental impact. This indicates the need of the evaluation of the modified materials effect on the total environmental burden over their life cycles.

Therefore, the main purpose of this work is to quantify the environmental impacts related to the mixtures of concretes in using life cycle assessment (LCA) for 30 years, 10 m^3 of concrete sets as a functional unit. The assessment tools available in construction field are based on different evaluation methods. ATHENA estimator is used in the current study, in which the environmental impact is calculated per unit weight of materials, it requires to weight for different impacts by the user.

For Life Cycle Assessment (LCA), the Standard (ISO) 14040 [11] is used, allowing the evaluation of material and energy flows, as well as potential environmental impacts during the life cycle of concrete. The effects of the replacement of fine and coarse natural aggregates such as gravel and sand in concretes, is investigated through energy demand and potential environmental impacts as change climate, eutrophication, acidification, particulate matters, smog potential, ozone potential depletion...

2. Experimental program

These experimental measurements were already published before [12-14].

2.1. Materials

2.1.1. Natural aggregates

All natural aggregates used in this study are produced in North of Algeria in Sidi Bel Abbes and are used by most of the constructors in this region.

- The used sand is Silicious, its granular class is 0/5mm. This sand is rich in fine elements (mixture of fillers), this is essentially due to the fact that all the Algerian crushing stations, don't proceed to removing of fillers or washing sand [12].
- Gravels are crushed aggregates with a measured density of about 2700 kg/m^3 and a granular class of 3/8 and 8/15mm.
- All mixes are prepared using Ordinary Portland Cement (CEMII/B 42.5 N NA 442). The mineralogical constituents of this cement are shown in table 1.

Table 1
Mineralogical constituents of cement [13]

Constituents (%)	C_3S	C_2S	C_3A	C_4AF
	58 to 64	12 to 18	6 to 8	10 to 12

2.1.2. Recycled aggregates

Tires are composed mainly of natural and synthetic rubber; it is difficult to know their exact compositions because of the secrets of the companies of their production. Figure 1 present rubber aggregate and crumb rubber used in this study.

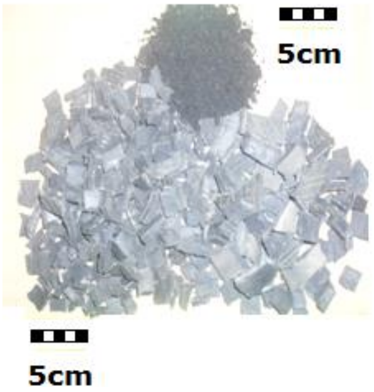

Figure 1. Recycled aggregates.

The used rubber aggregates contain more synthetic rubber than natural rubber, in addition to a percentage of non-rubbery elements such as metal and textile.

- Rubber aggregates used as partial replacement of coarse aggregates have size between 1 to 40 mm, having a density of about 1.2. These aggregates are obtained by manual shredding.
- Crumb rubber is used as partial replacement of fine aggregates has size between 1 to 4 mm and a density of about 1.3.

2.1.3. Water

The water used in this work, is a drinking water. No analysis has been done, considering that it is clean water intended for consumption. Water/Cement ratio is about 0.5.

2.2. Samples of Concrete

The recycled aggregates are incorporated in studied mixtures in two ways (Table2). The first mixture (*CRg*) is formulated with 5%, 7.5% and 10% of rubber aggregates in partial replacement of coarse aggregates. The second one (*CRm*) is prepared with 5%, 5.7% and 10% of rubber aggregates, in partial replacement of coarse and fine aggregates. These mixtures are compared to ordinary concrete with 100% of natural aggregates.

The letter (*C*) indicates Concrete, (*R*) indicates rubber aggregates replacing a gravel fraction of aggregate. (Rm) indicates rubber aggregates and crumb rubber replacing gravel and sand while (n) indicates ratio of substitution [13]. For example, (*CRg10*) is concrete incorporating 10% of rubber aggregates in replacement by weight of gravel. (*Cref*) indicates ordinary concrete (without replacement). As shown in table 2, the cement content is constant (380 kg/m^3).

The study of these compositions (*CRm* and *CRg*), released by Medine *et al.*, indicated that their density is ranging between 2360 kg/m^3 and 2275 kg/m^3, the slump test showed that these concretes are firm (S=5 cm).

These concretes have the same compacting classes, their segregation resistance is acceptable as compared to an Ordinary lightweight concrete [13]. The investigation carried on cylindrical (16×32) mm and prismatic (10×10×40) mm samples (Figure 2) of these concretes indicated a decrease in compressive strength and an increase in their ductility and deformability because of the decrease of elastic modulus. It has been demonstrated that these characteristics improve in time [12]. The tested concretes resisted to aggressive agents (attack of acid), elevated temperature and freeze-thaw [14].

Figure 2. Specimen of studied concretes [12]

Table 2
Mixture design of 1 m^3 of concrete [12]

Concrete	Materials (kg/m^3)					Water (L)
	Cement	Rubber aggregate	Crumb Rubber	Sand	Gravel	
C ref	380	0	0	858	927	190
*CRg*5	380	46.4	0	858	884	190
*CRg*7.5	380	69.5	0	858	851	190
*CRg*10	380	93	0	858	839	190
*CRm*5	380	46.4	42.9	815	884	190
*CRm*7.5	380	69.5	64.35	793.65	851	190
*CRm*10	380	93	85.8	772.2	839	190

3. Life cycle Analysis of rubberized concretes

3.1. Goal and Scope definition

The Life Cycle Assessment (LCA) methodology according international standards ISO 14040 [11] allows not only the quantification of current environmental profiles but also the identification of improvement potentials in order to reduce future environmental impacts. LCA studies typically identify the most important contributors to the environmental impacts, which allow focused effort on reducing those impacts [15]. In this step the different compounds are translated from inventory analysis into impact categories [16].

The objective of this work is to quantify the environmental performance of rubberized concretes and to compare it with ordinary concrete. This type of study is not found in the literature, this made this analysis difficult due to the lack of primary data. These rubberized concretes are manufactured for use in non-structural applications such as paving. It is supposed that these concretes are manufactured by local companies.

The choice for the functional unit can facilitate the comparison among the whole case studies [17]. All inputs and outputs will be developed in relation to this unit. The functional unit used in this study is defined as 10 m^3 of concrete. This choice was made due to the low proportions of the aggregates substituted from the mixtures. We considered also a standard area of 100 m^2

as the area of produced element and a thickness of 0.10 m without any coating. The reasons for these choices are that ATHENA estimator provides calculations for a building and 100 m^2 and 10 m^3 are acceptable as input for this tool of estimation.

The LCA process has three major stages, building materials production phase, use phase, and end-of-life phase [18]. The life cycle of the studied concretes includes all processes for obtaining raw materials (minerals extraction and transformation) and manufacturing concretes. It covered the transport of materials, the production of concrete and its transport from the concrete plant to the construction site. The stages of the use and the end of life (reuse, recycling, destruction, and storage) are excluded from the analysis since the various concretes are intended for the same use and fulfill conditions of comparable durability, in addition to the lack of precise information in this sense. Environmental assessment of all cases has been obtained by using ATHENA ESTIMATOR containing a wide range of options that facilitate the achievement of results.

The tested materials would serve a period of about 30 years. The life cycle analysis in this study is of a comparative type, whose common elements have been excluded from the life cycle such as earthworks, traffic and lighting.

The effects of resource use and the emissions generated are pooled and quantified in a limited number of impact categories, and can be weighted according to their significance.

Each inventory item is assigned to an appropriate impact category. The life cycle analysis of concretes in this study includes the categories: warming effect, eutrophication, atmosphere acidification, resource consumption, consumption of fossil resources (energy) and consumption of mineral natural resources.

An assessment of cumulative energy demand (CED) is a good point in an environmental assessment, because of the simplicity of its concept and its comparability with the results of other studies [19].

3.2. Life Cycle Inventory (LCI)

The inventory analysis is the most important stage in the process of LCA [17]. After defining the goal and the scope of the assessment, as well as the system boundaries, all type and quantity of incoming and outgoing are inventoried. The emissions are modelled in an LCA in terms of instantaneous cumulative releases into the air, water and soil [16].

The Life Cycle Inventory (LCI) data for the various materials is not yet all available, which necessitate a collection of data closest to the reality of the case studied in order to have the most consistent results.

The data collected is linked to the functional unit [20]. The environmental impacts of each composition of concretes (Table 2) until they arrived at the site are calculated using ATHENA estimator. For each process, all inputs are introduced including the consumption of materials and energies involved in the production of these concretes.

Data of mineral aggregates, cement and water such as different energies required: fuels, petrol and diesel, electricity and natural gas and their transport cannot be collected from local companies and manufacturers; they are available and taken account in ATHENA database. The processes of their production and extraction are based on Canadian conditions and cannot be modified, while those relating to the production of concretes (mixing, transport, execution) are collected from the literature. The energy needed in the process of crushing tire rubber has been deduced from the technical sheets of crusher rubber (132 kw/h, 20 ton/day) since no primary data were available in this case.

In this work it has been accounted the consumption of energy resources and natural resources according to the quantity of materials used. This calculation takes into account the energy consumed in each process; the production of concretes and its transport to the site, the use of construction equipment on site and the energy required for their execution. It is supposed that the concretes of this study are manufactured in a power station and then transported to the construction sites. The energy consumed for this operation is supposed to be 0.025 GJ/ton (0.06 GJ/m^3 of concretes); hypothesis drawn from the literature [19].

For transport, the energy consumed attributable to the concretes studied, is accounted according to the distance, the types and capacities of the means used to reach the construction sites are not specified. This study is of a comparative type, the elements common to the two systems have been excluded; the analysis is made only on the difference between compositions.

Concrete is supposed to be transported by truck to sites 30 km from the concrete plant, where diesel fuel is assumed to be the main fuel used. Vibration energy and compaction of cast-in-place mixtures are excluded from the calculations as they are practically negligible.

The database of weighing and mixing of the components, transport to the construction sites and execution of concretes are taken from [21]. Emission data for diesel production and transportation, couldn't be collected for local conditions, they are taken from ATHENA database.

4. Results discussion

The aim of this study is to compare the environmental impact of rubberized concretes to an ordinary concrete. The comparing of the results of this research work to previous work can be effective if the components of the tested material and the life cycles are similar and include the same steps with the same points of start and end.

4.1. Life cycle Impact Assessment of Concretes

In this step the results obtained for environmental indicators using ATHENA estimator are presented and described. They allow the comparison of the environmental impact assessment of the different concretes, based on the data inventory described previously.

The diversity of the cementitious composites characteristics is generally due to the diversity of the processes and techniques of recycling; this makes the comparison of the results obtained in this work with those noted in prior studies.

The environmental impact from selective and conventional impact categories is calculated to find out the influence of these concretes on environment.

4.1.1. Climate change

Climate change is estimated in kg CO_2 eq being the standard substance for this impact category. Compared to the ordinary concrete as shown in figure 3, a low reduction of about 0.24 to 0.48% per functional unit is observed in the case of the composition (*CRg*) and of about 0.73% in the case of all concretes of the composition (*CRm*). The possible explanation for these results can be the low substitution rates of mineral aggregates.

These emissions are due to cement production. As given in table 2 high cement amount has been used (380 kg/m^3) in the different studied mixtures. We note that one of the ways for limit CO_2 emissions is to use less amounts of binders.

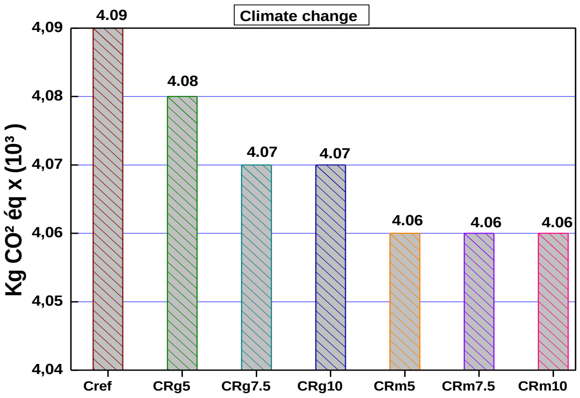

Figure 3. Concretes contribution to the climate change.

Marinkovic and al [22] studied concretes containing recycled aggregates, they found that this impact was of about 332 kg CO_2 eq per 1 m^3, this result is slightly lower than the results obtained in the case of the tested concrete compositions (we note that the case studies are not similar in terms of mixture and scenario production). According to the ADEME report, transport by dump truck generates around 200 g of CO_2 eq per ton of material transported over a distance of one kilometer [23]. It is very important to take into account the distance between the aggregate production site and the concrete production site. Indeed, the CO_2 impact generated by the transport of aggregates to the concrete production site becomes greater than that of the manufacture of aggregates from 15 km [24]. It was proved in [25] that one cubic meter (1m^3) of concrete weight approximately 2400 kg, 100 to 300 kg CO_2 eq is embodied and 309 kg CO_2 eq/m^3 in [26] studying production process of Korean concrete (24 MPa), and so all analysis results are depending on the mix design.

4.1.2. Acidification potential

This impact is expressed in kg SO_2 eq. Figure 4 summarizes that the founded results are slightly different. The comparison of these results showed that the generation of this emission has been reduced of about 0.51 to 1.03% per functional unit for the composition (*CRg*) and about 1.54% for the composition (*CRm*).

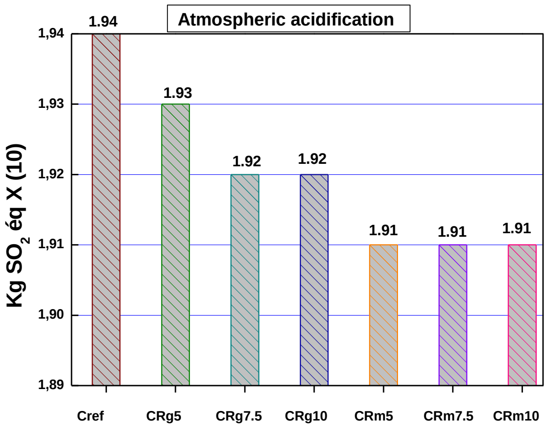

Figure 4. Concretes contribution to the acidification potential.

This indicate that the effect of total emissions of acidic gases (SO_2, NO_2, HCl...) on air, soil and water as well as building corrosion has been reduced. The results obtained in the case of the composition (*CRm*) is about 1.91 kg SO_2 eq, Tae and al [27] analyzed the impact of the substances emitted during the production process of concrete (24 MPa), they found that the biggest impact on acidification was coarse aggregate and fine aggregate, the emitted substance was about 27.9 kg SO_2 eq . In this study, the decreases of emissions are related to the quantities of substituted aggregates. The release of particulates is resulting from the combustion of fossil fuels and raw material containing sulfur [28].

4.1.3. Particulate matters

As can be seen in figure 5 the pollution by toxic emission of particulate matter, described in kg PM2.5 eq, has decreased of about 0.88 to 1.76% per functional unit in the case of the composition (*CRg*) and between 2.35 to 2.65% per functional unit for the composition (*CRm*). As the cement content is not reduced the decrease of the human toxicity impact is not significant. Most of these particulates are generated by the extracting process and the consumption of fuel needed for the transportation and production of materials; cement in particular.

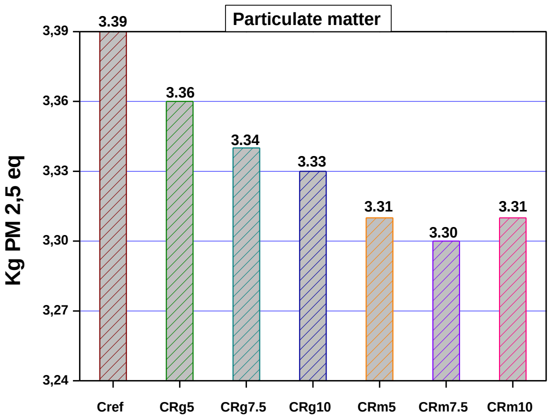

Figure 5. Concretes contribution to the generation of particulate matters.

4.1.4. Eutrophication

The partial substitution of gravel and sand has affected the Eutrofication potential estimated in kg N eq. This impact reduces the oxygen in water and is affected by the discharge of washing and cleaning water from construction sites located near water surfaces. This mechanism is responsible for the contamination of these waters.

As shown in figure 6, a reduction of about 0.87 to 1.62% per functional unit is recorded in the case of the composition (*CRg*), this reduction is about 2.36% in the case of (*CRm*5), (*CRm*10) and 2.62% in the case of (*CRm*7.5). These results suggest that the surface waters at neighbour hoods of construction sites are less affected by this type of pollution.

The reduction of this impact of both compositions can be explained by the amount of used raw materials.

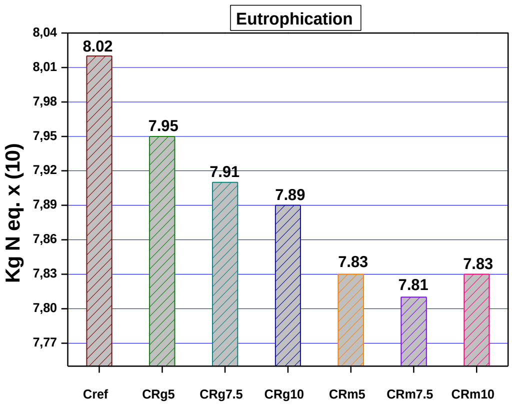

Figure 6. Contributions of the concretes to the eutrophication.

4.1.5. Destruction of the stratospheric ozone layer

Estimated in kg (CFC-11) eq per kg of emissions (selected by ATHENA among 23 types of materials: CFC-11, Halons, 1301, CFC114...) and suggested by the World Meteorological Organization [29] as reference material. In the case of this work, the mixture (*CRg*) shows a reduction of about 0.5 to 1.17% and between 1.68 and 1.84% for the mixture (*CRm*) (Figure 7).

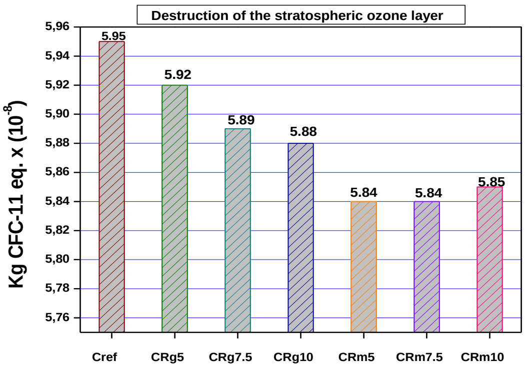

Figure 7. Concretes contributions to the destruction of stratospheric Ozone layer.

The studied rubberized concretes are less impacting on the destruction of stratospheric ozone layer (5.84 10^{-8} kg (CFC-11) eq per functional unit) than the ordinary concrete. Regarding this impact, it was proved in [26] that the substances discharged from concrete production process are 4.9 10^{-5} kg (CFC-11) eq /m^3.

4.1.6. Photochemical ozone creation

The results of this impact are reported in kg O_3 eq. These results show a lower impact in the case of the rubberized lightweight concretes as compared to the ordinary concrete made entirely with natural aggregates.

In regards to the formation of the harmful agents that are responsible of summer smog formation above the areas of their use, the reduction of these agents is between 1.16 and 2.03% per functional unit for the composition (*CRg*) and between 2.9 and 3.2% for the composition (*CRm*) (Figure 8). Almost of these emissions are caused from burning fossil fuels.

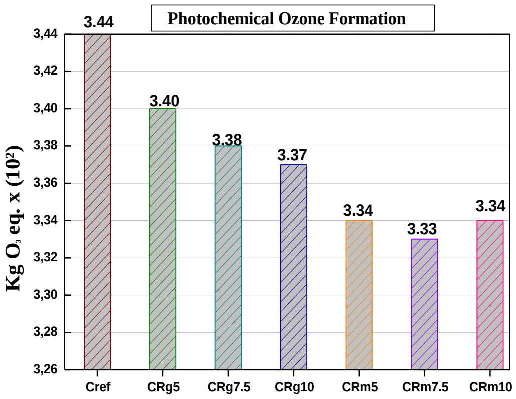

Figure 8. Concretes contributions to photochemical ozone creation

4.1.7. Primary energy consumption

The total primary energy consumed during the extraction and the production of materials, estimated in MJ, is reduced by approximately 0.82 and 1.09% per functional unit for composition (*CRg*) and (*CRm*), respectively (Figure 9). The low amount of substituted aggregates in the studied mixtures allowed the reduction of non-renewable energy consumption by approximately 0.28 to 0.57% for the composition (*CRg*) and 1.15% for (*CRm*).

These energies are consumed by the equipment used in the energy intensive processes for obtaining raw materials and the manufacture of concretes; it is more important in the case of the ordinary concrete and less significant in the case of the composition (*CRm*). The required energy (Figure 9) is less than these recorded in [25], it was indicated that the production energy of concrete is about 1.4 GJ/ton.

Generally, this consumption is also on the means of transport, the distance between the stock of materials, concrete plant and the construction site.

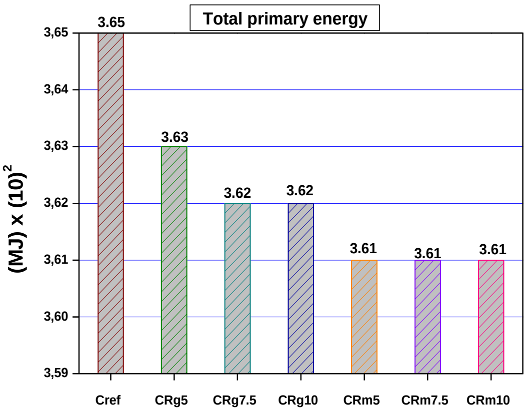

Figure 9. Concretes contribution to primary energy consumption.

4.1.8. Consumption of fossil fuels

In this work, the consumption of fossil fuels is reduced by a maximum of about 1.46% corresponding to the composition (*CRm*). No significant reduce has been recorded in this impact since the quantity of the substituted materials is also small. It would be more significant if the substitution rate is greater (Figure 10).

This impact is much related to the cumulative energy demand. It is mainly due to the production of the binder and the transport phase [30]. This was confirmed in the study of Braymand and al [31], whose the influence of composition and transport parameters has been studied. If the same cement content is used, the use of recycled aggregates to replace natural aggregates does not significantly modify the LCA of concrete compositions.

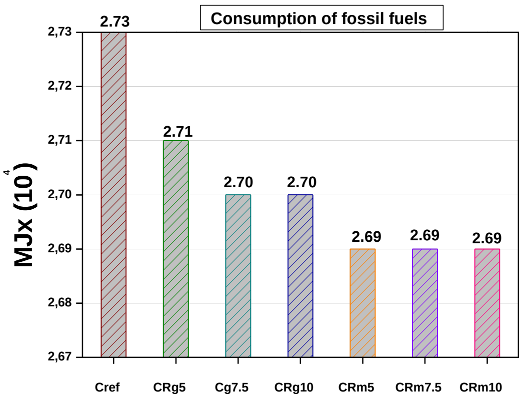

Figure 10. Concretes contribution to consumption of fossil fuels

4.1.9. Cumulative energy demand

In regard to the cumulative energy demand, a simple calculation was made according to each step or process included in the previously defined boundary of this study. The results of this impact (Figure 11) show that, the cumulative energy demand in the case of ordinary concrete is greater than that required in the case of a rubberized concrete of the composition (*CRm*) in particular (a reduction of about 6% in the case of (*CRm*10). This can be due to that the transport of aggregates and concrete to construction sites demands more energy, despite the fact that the transport of employees (workers and site managers) is not taken into account in the calculations.

This assessment considers fuel production and combustion during transportation of the mixtures from the production site to the construction site.

Even if the process of the granulation of tires rubber required more energy; the energy use during this process was less compared to that consumed for extraction of raw materials.

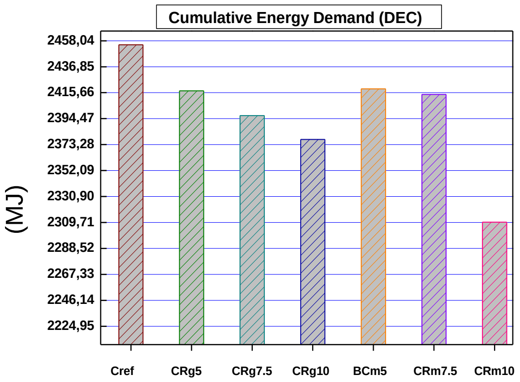

Figure 11. Concretes contribution to cumulative energy demand

According to Esin [32], each step in the material manufacturing process requires transportation and involves energy consumption up to 2.2% of the overall life cycle.

It can be seen on figure 11, that the energy demand is less important in the case of the concretes having a lower density. These results prove also the proportionality of these two parameters to each other.

5. Conclusion

The main objective of this study is to evaluate the formulation proposed for the production of modified concrete with the incorporation of rubber aggregates. In order to study the impact of these concretes on the environment, we focused on this objective by maintaining the fixed dosage of the cement and identical transport distances.

This study made it possible to compare the emissions generated and the energy consumed in the life cycle of the concretes studied, in which 5%, 7.5% and 10% of fine/coarse natural aggregates were replaced and an ordinary concrete entirely made with natural aggregates.

The results show that the substitution of a quantity of natural materials for their replacement by rubber aggregates induces a reduction of the environmental impacts of concrete. This decrease is small due to the cement content kept constant, the low substitution rate and the exclusion of the use and end-of-life phase in this study, due to the lack of information on energy consumed or saved during these two phases.

Life cycle analysis shows that the various environmental impacts are more or less reduced compared to ordinary concrete, this reduction is moderate but questionable. The comparison of the two compositions (*CRm*) and (*CRg*) shows that the first, in which the gravel and sand have been substituted, produced less impact, therefore a higher substitution rate produces less impacts.

The energy requirements for the production of concrete, their implementation and their transport are reduced in proportion to the density of each mixture.

In the concrete production process, fine and coarse aggregates have the greatest impact on acidification and eutrophication, as well as all other impacts. The process of producing materials requires transport and requires energy; this step is the most impactful.

The most important impacts that we need to reduce are the climate change, the consumption of energy and the consumption of fossil fuels. These impacts are less in the case of the composition (*CRm*); (*CRm*10) in particular, in which the largest quantity of mineral aggregates has been replaced by rubber aggregates. It should be noted that these conclusions are specified for the concretes of this work, therefore they cannot be generalized.

The goal of any innovation is to find a compromise between technical feasibility, production cost and quality of the finished product. Future research on an economic impact analysis is absolutely necessary.

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