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Concrete in Brazil: Brief history, current challenges, and proposals for a sustainable future

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ABSTRACT

The concrete production sector is fundamental in civil construction and human activities in general, being the most abundant manufactured product in the world. Its production generates environmental consequences and contributes to the acceleration of climate change. This work aims to identify modern solutions for sustainable concrete production through the incorporation of recycled materials. Initially, an exploratory study of a documentary nature was carried out on the history of concrete, in order to identify the main characteristics that led to its widespread adoption. Then, a literature review was conducted on studies that seek to overcome the problems of concrete, with a focus on the incorporation of materials from various sources. Finally, with the data at hand, the similar aspects of each proposal were compiled, and it was observed that, despite the negative effects on the original characteristics of the product, concretes with recycled materials still have compatible characteristics that allow their mass adoption. It is concluded that the incorporation of alternative materials in concrete has a high potential for waste recycling and can contribute to the production of a more ecological concrete, without excessively compromising its fundamental characteristics.

KEYWORDS: Concrete. Waste. Building Materials

1 INTRODUCTION

Concrete is a material composed of a mixture that includes a binder, with Portland Cement (PC) being the most common, water, Fine Aggregate (FA), typically sand, and Coarse Aggregate (CA), commonly gravel. This relatively straightforward combination yields a versatile material capable of withstanding and transmitting high-intensity loads, while also resisting adverse weather conditions.

In the construction industry, concrete stands out as the subfield with the highest production volume (LASCARRO, 2017), to the extent that it can be considered the most abundant manufactured product on Earth (PEDROSO, 2009). The introduction of concrete in Brazil marks a significant milestone for the country's engineering and architecture. The product was quickly embraced by both the market and academia. According to VASCONCELOS (1992), the study of concrete was already being conducted in universities in the 1940s, with official standardization by the Brazilian Association of Technical Standards (ABNT), and widespread utilization in civil construction.

However, along with the exponential increase in the use of PC concrete, there has also been a growing concern regarding the sustainability of its production. The most commonly raised issues include the high volume of carbon dioxide (CO_2) emissions and the generation of solid waste resulting from inefficiencies in the production chain and building demolitions.

In light of this situation, proposals have emerged for the utilization of alternative materials in concrete production, aiming to mitigate environmental damage while maintaining the characteristics that have made concrete a dominant material. This approach holds appeal from both the perspective of reducing the impacts caused by the production of PC, FA, and CA, and from the standpoint of managing solid waste that would otherwise go unutilized.

2 OBJECTIVES

The objectives of this study are to comprehend and evaluate the characteristics that have led to the extensive use of concrete in Brazil, as well as to identify the main current challenges related to the material. Finally, potential solutions will be described for the utilization of alternative materials in concrete, aiming to mitigate the environmental impact of its production while maintaining the advantages of the product.

3 METHODOLOGY

To identify the key characteristics that have historically contributed to the success of concrete as a material, diverse and dispersed sources were consulted. This involved conducting a comprehensive literature review and documentary research using well-established scientific databases. The primary focus was on studying the introduction and early utilization of concrete in Brazil. Furthermore, the research aimed to uncover the main challenges and environmental impacts associated with the extensive use of concrete. This involved analyzing the existing literature and documented evidence to understand the historical context and current concerns related to concrete production and application. Finally, the study examined potential solutions and alternatives for the future of concrete, considering approaches that can be implemented on a large scale while preserving the advantageous characteristics that have historically made concrete widely used in the construction industry, with the goal of reducing environmental impacts.

4 RESULTS

4.1 Literature review

4.1.1 The history of concrete

There is evidence of concrete usage dating back to 2750 B.C. in Egypt (HELENE, ANDRADE, 2010). However, the first recorded large-scale use of this material dates back to 300 B.C. in the Roman Empire, where a mixture of volcanic ash (pozzolana) and hydrated lime was used, which hardened upon contact with water (PEDROSO, 2009). One of the most famous Roman structures that utilized this material was the Pantheon, completed in 125 A.D. The Pantheon is notable for still having the world's largest unreinforced concrete dome to this day (WARD-PERKINS, 1992).

Although the use of rudimentary binders is ancient, according to FREITAS (2011), the English builder John Smeaton, along with the ceramicist and chemist William Cookworthy, were the first to scientifically study cement. According to PETERS (1996), their research led to the discovery that the hydraulic properties of cement were not dependent on the origin or purity of the limestone, but rather on the addition of silicates through clay.

These findings had a significant influence on subsequent research on the subject. As research on concrete production progressed, an increasing number of binding materials emerged, collectively referred to as cement. In 1796, James Parker, an Englishman, observed that pieces of exposed limestone, when subjected to a certain temperature, hardened. He named this product "Roman cement" (FREITAS, 2011).

On the other hand, the use of PC dates back to 1824 in England, when Joseph Aspdin officially patented the product (PEDROSO, 2009). Aspdin's product was the result of burning limestone and clay, followed by grinding and exposure to high temperatures until carbon dioxide was removed. While most sources attribute the invention of PC to Aspdin, author FREITAS (2011) highlights the contribution of Isaac-Charles Johnson to laying the foundation for the manufacturing process of artificial PC, which served as the basis for industrialization and subsequent production of modern cement. However, KAEFER (1998) adds that the contemporary definition of PC cannot be applied to the product patented by Aspdin, as it is unlikely that the inventor was able to expose the raw materials to a high enough temperature to produce clinker.

The current industrialization process of PC production involves the production of clinker through the crushing and grinding of limestone, clay, and gypsum. Subsequently, the clinker is subjected to high temperatures (±1500°C) and rapidly cooled.

The history of PC usage continues to evolve with the proposition of using concrete in combination with iron bars. KAEFER (1998) attributes the first publication on "reinforced cement," the previous name for reinforced concrete until the 1920s, to Joseph Louis Lambot in 1850. Lambot patented the material in 1855 and showcased a prototype canoe made of reinforced concrete at the World Exhibition in Paris. One of the most well-known milestones in the evolution of reinforced concrete occurred when Joseph Monier constructed the world's first reinforced concrete bridge in 1875 in France (MOUSSAR, GARIBALDI, 2017).

4.1.2 The concrete in Brazil: Introduction and establishment of hegemony

Concrete was commercially introduced in Brazil in the early 20th century, by foreign companies (VASCONCELOS, 1992). By the 1940s, concrete had already become well-established in the academic sphere, with standardization by the Brazilian Association of Technical Standards (ABNT), and it had become an integral part of engineering courses as well as widely used in popular construction practices (SANTOS, 2008). However, in the late 19th century, the engineer Cornélio Carneiro de Barros e Azevedo published the work "Auxiliar do Construtor," the first technical manual for construction professionals that provided definitions of cement and concrete.

Initially, the first cements used in Brazil were imported, mainly from Belgium. However, by the 1920s, there were already five PC production factories in the country, their establishment greatly aided by proposals for public subsidies. The use of concrete and, consequently, reinforced concrete techniques played a crucial role in the construction of sanitation infrastructure and the improvement of people's quality of life. The initial applications of this technique were seen in infrastructure projects built in the port city of Santos, the main gateway for imported products, including concrete made with PC at the time (MARCOLIN, 2006). Another advantageous aspect of the material was its logistical ease, as the transportation of PC, sand, and gravel was much less costly than transporting large steel beams, especially considering the logistics infrastructure in Brazil at that time (TELLES, 1994).

The authors HELENE and ANDRADE (2010) emphasize that one of the main advantages of concrete structures is their long service life and minimal maintenance requirements, which is beneficial from a financial standpoint. For instance, the statue of Christ the Redeemer in Rio de Janeiro, designed by engineer Heitor da Silva Costa in collaboration with French designer Albert Caquot and inaugurated in 1931, has only required two maintenance interventions throughout its history.

From an architectural perspective, the popularization of concrete in Brazil was driven by its use in Modern Movement architecture, particularly from the 1940s to the 1960s (SANTOS, 2008). Iconic structures such as the São Paulo Museum of Art (MASP) completed in 1968, the construction of Brasília in 1960, and the building of the Faculty of Architecture and Urbanism at the University of São Paulo (FAU USP) in 1948 exemplify the significant use of concrete in Brazilian modern architecture.

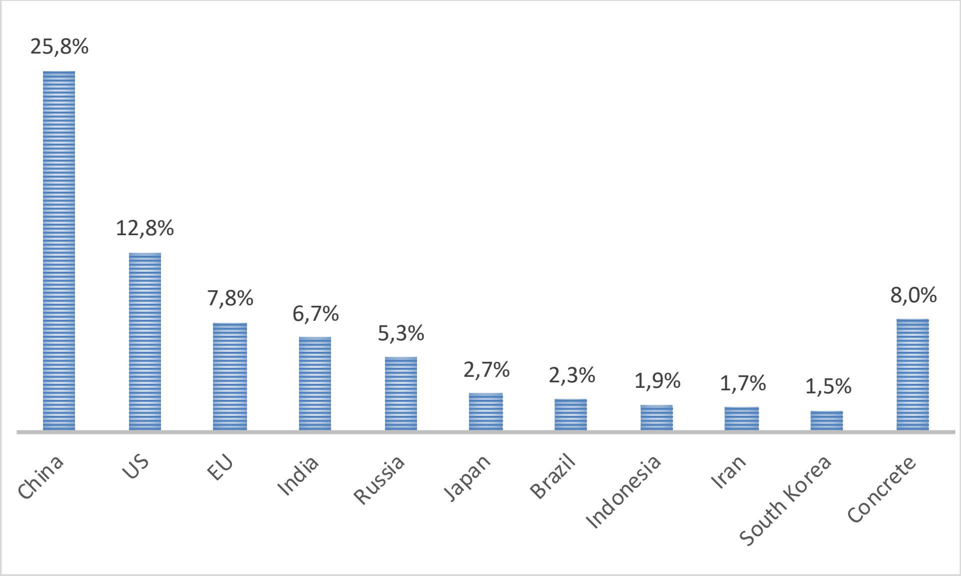
4.1.3 Current challenges of the use of concrete

Reinforced concrete played a significant role in improving infrastructure and modern architecture in Brazil. However, its widespread use hindered the introduction of modern construction techniques, leading to the disqualification of workers and contributing to increased environmental pollution. Furthermore, from an architectural standpoint, it led to the uniformity of the urban landscape, diminishing diversity and dialogue between buildings and their surroundings.

The construction system is still considered technologically outdated, relying on serial manufacturing. Its use faces environmental challenges related to the consumption of natural resources and the negative consequences of extraction, transportation, storage, and disposal.

From an environmental perspective, there is particular concern about the high proportion of CO_2 emissions generated by its production chain. According to researchers LEHNE and PRESTON (2018), global concrete production accounts for 8% of all CO_2 emissions produced annually worldwide. This result is 14% higher than the average of the top 9 CO_2-emitting countries in the world, along with the European Union (EU) (CLIMA WATCH, 2022).

Figure 1 – Percentage of emissions from concrete and the top 10 CO_2-emitting regions.



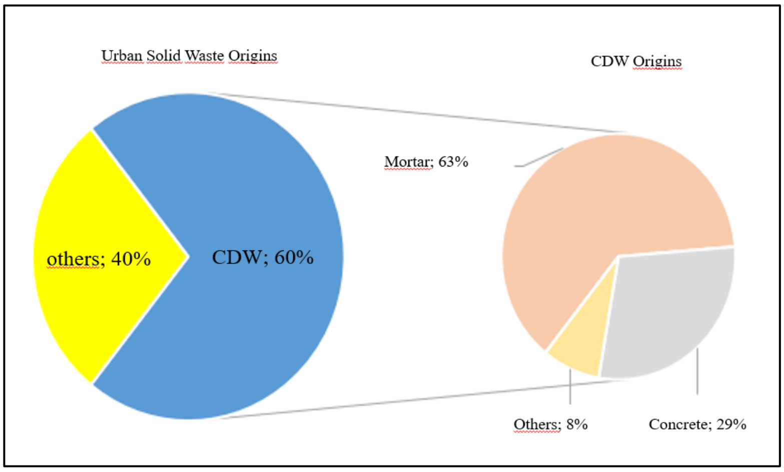
Source: Authors (2023)

The majority of emissions are concentrated in the production of PC, with 40% of PC emissions associated with the burning of fossil fuels to heat the kilns that form the clinker (BRITO, KURDA, 2021).

While most emissions from concrete production are concentrated in the production of PC, aggregates also account for a significant portion of concrete's CO_2 emissions. According to estimates by Flower and Sanjayan (2007), aggregates are the second-highest emitting material in concrete production, ranging between 13% and 20% of the total emissions generated. The production of aggregates, particularly natural sand, emits a significant amount of CO_2, with emissions concentrated in the extraction process (SIDDIQUE, 2021).

In addition to issues related to the production and use chain, there is currently a concern about the disposal of waste generated by concrete. In Brazil, in 2021, approximately 60% of all urban solid waste was derived from construction and demolition activities, primarily from building demolitions, averaging 226.8 kg per capita per year (ABRELPE, 2022). In most cases, Construction and Demolition Waste (CDW) consists of residues from cement-based materials such as mortars, concrete, and blocks (SILVA FILHO, 2005). When specifically analyzing CDW derived from concrete residues, researchers Ângulo et al. (2011) estimate that up to 50% of all CDW produced comes from concrete remnants, while MONTEIRO et al. (2001) estimate that concrete waste accounts for approximately 29% of the total CDW in Brazil. One of the main difficulties related to concrete waste is its limited recycling capacity, which is due to both the large volume and weight of demolished pieces and the lack of appropriate destination for recycled material. This problem represents a significant obstacle to achieving circularity in the construction industry, which is a concept that seeks strategies to overcome the linear extraction, use, and disposal logic of the traditional economy. Concrete waste derived from cement-based materials is such a relevant issue that it is classified as "Class A" waste in Resolution 307 of the National Environmental Council (CONAMA), which allows it to be used as recycled aggregate (CONAMA, 2002). This classification is important as it expands the possibilities for the use of the product, demonstrating the government's interest in promoting its reuse.

Figure 2 – Solid waste generators in Brazil



Source: Authors (2023)

Given the current challenges related to concrete and in accordance with various legal regulations, numerous proposals for sustainable options aiming to make the concrete of the future a more circular material in terms of natural resource use have been gaining prominence in the scientific community..

4.2 Proposals for sustainable innovation in concrete

4.2.1 Utilization of agroindustrial waste ashes as binder substitute

Among the various types of agricultural waste that can be utilized, rice husk ash (RHA) stands out. According to PANDEY and KUMAR (2019), this material has low economic value and enhances the compressive strength of the final concrete when used as a binder in conjunction with microsilica (MS). Studies have shown that the amount of silica present in RHA is about four times higher compared to PC. Furthermore, its reuse is appealing as it is a byproduct of rice generated in large quantities by rice-producing countries, most of which are located in the Asian continent.

Similarly to RHA, ashes from other sources also contain a high presence of silica. However, tobacco ashes and peanut shells exhibit values below the average of most materials tested and reviewed by Charita et al. (2021). The same authors identified that the addition of agro-residue ashes from any source impairs the workability of concrete due to an increase in the number of pores, consequently leading to increased water absorption by the fresh concrete paste. In the same article, it is further concluded that considering the optimal point of substitution of PC with ashes, both compressive strength and resistance to chemical attacks tend to increase.

4.2.2 Utilization of tire rubber waste as fine aggregate

Although there is a high volume demand, less than 0.20% of the mass of tire rubber produced in Brazil is recycled (FAZZAN, PEREIRA, & AKASAKI, 2016). This large amount of non-recycled material makes tire rubber a product that can supply high quantities for use as FA. The utilization of rubber as aggregate is further driven by the fact that FA, unlike PC, does not participate in the hydration process, which significantly reduces the complexity required for material adaptation for use (SHI, ZHENG, 2007).

One of the most important aspects for a material to be classified as fine aggregate is its particle size distribution, which determines the distribution of particle sizes in the material. In the study conducted by FAZZAN, PEREIRA, and AKASAKI (2016), samples of tire rubber were prepared and divided into coarse, medium, and fine rubber to be used as FA in concrete. The material was close to being fully within the usable particle size range, deviating from it in only three out of the eight points analyzed.

For a specimen with 10% volume replacement of FA with tire rubber, researchers found results indicating that the addition of rubber resulted in a reduction in water absorption values. Additionally, the low density of rubber leads to a decrease in the specific mass of the final product, suggesting that structures using this material would have less self-weight and could be more slender. Regarding compressive strength, the product showed a 10% improvement compared to the control, with a slightly higher modulus of elasticity compared to the product without waste addition (FAZZAN, PEREIRA, & AKASAKI, 2016).

4.2.3 Proposed production of lightweight structural concrete with EPS addition

The structural function of concrete is one of its most well-known and utilized characteristics. The versatility of the material in being used for columns, beams, and slabs is a highly exploited property in architecture and engineering. However, concrete structures not only need to withstand the loads imposed by usage but also support their own weight. This factor leads to increased material and economic costs. One alternative to address this is the use of lightweight structural concretes, which are materials that maintain similar strength characteristics while having reduced specific mass (CATOIA, 2012).

An example of this type of research is the study conducted by XAVIER, BASSANI, and MENDES (2016), which investigated the possibility of adding recycled EPS for the production of lightweight concrete that can be classified as structural while having a lower specific mass. The authors used EPS waste from a construction site located in Palmas-TO. The reference mixture consisted of high-performance concrete with silica and a superplasticizer additive. The addition of EPS was done in portions of 0.0091 m^3 (T1), 0.02 m^3 (T2), and 0.04 m^3 (T3) of EPS.

The characterization of the recycled material revealed that EPS predominantly consists of spherical particles measuring 5 mm in diameter, with a specific mass of 11 kg/m^3 (XAVIER, BASSANI, MENDES, 2016).

The results indicate a significant reduction in the specific mass of the concrete produced with the addition of recycled EPS in mixes T1, T2, and T3. The concrete produced with mix T3 experienced a reduction of 0.58 kg/dm^3 in its specific mass, allowing it to be classified as lightweight concrete according to the references of ACI 213R-87 and NS 3473 E. Mix T2 can also be considered lightweight according to NS 3473 E, with a reduction of 0.37 kg/dm^3 compared to the control. A decrease in the slump test values was also observed, indicating a decrease in workability of the mix with the addition of EPS. While the control mix exhibited a slump of 70 mm, the mixes with EPS resulted in slumps of 60 mm (T1 and T2) and 40 mm (T3).

Furthermore, regarding the compressive strength at 28 days, there was a reduction in values for all the mixes. While the control mix achieved an average strength of 61.40 MPa, the mixes with EPS obtained values of 46.20 MPa (T1), 21.0 MPa (T2), and 12.30 MPa (T3). This aligns with the authors' expectations since a higher addition of EPS has a greater negative effect on the concrete's strength. Based on the obtained results, it can be concluded that mix T2 was the only mix with a specific mass classified as lightweight concrete that achieved a strength exceeding 20 MPa. Therefore, it can also be classified as structural concrete. Additionally, according to the researchers, there was an increase in water absorption due to the increased voids surrounding the EPS particles.

4.2.4 Simultaneous Substitutions in Binder and Aggregate: Glass Fibers and Coconut Husk

Unlike previous proposals that focus on the substitution of binder or aggregates, some efforts aim to produce concretes using combined recycled materials. This approach has the advantage of reducing the need for raw materials and increasing the utilization of discarded materials. One of the most notable recent works in this scenario is presented by researchers ZAID et al. (2021), who explore the use of Glass Fibers (GF) in the production of concrete with Silica Fume (SF) and Coconut Husk (CH) as a substitute for the binder.

Using the proportions mentioned in Table 1, the researchers formulated four mixtures, each incorporating the respective additions of recycled materials in substitution for what would be consumed in the production of the control mixture (ZAID et al., 2021). The results showed that the higher the rates of substitution of conventional materials with recycled materials, the greater the negative impact on the workability of the concrete. All the studied proportions exhibited a lower slump value compared to the control mixture. The largest decrease, of -20 mm, was observed in Mixture 4, which incorporated the highest percentages of recycled materials. On the other hand, except for Mixture 4, the compressive strength tests of the other three mixtures were higher than those obtained in the control mixture. Furthermore, it was observed that only Mixture 4 exhibited a density 22% lower than that of the control mixture, while the other proportions showed an increase in the density of the final product. The highest increase was observed in Mixture 3, which resulted in a 6% higher density compared to the control mixture.

The researchers emphasize that the addition of GF to concrete improves its durability. This is due to the fact that glass reduces the porosity of the material, which decreases the penetration of acids, providing a significant advantage in specific applications that require greater resistance to chemical attacks. Furthermore, through Scanning Electron Microscopy (SEM) analysis, the authors concluded that GF has a crack propagation reduction effect in concrete, which in turn reflects benefits for the mechanical strength properties of the material (ZAID et al., 2021). Similar indications are also found regarding the use of glass powder, which exhibits sufficient pozzolanic properties for concrete utilization and does not show the presence of cracks resulting from alkali-aggregate reaction (BRITO, KURDA, 2020).

This study highlights how the concrete of the future can be produced by incorporating different materials with specific objectives. The researchers found that using coconut husk exclusively as FA results in a product with moderate strength and general properties. However, when combined with silica and GF, which are industrial by-products, all concrete characteristics tend to be enhanced, potentially surpassing those of conventional products (ZAID et al., 2021). The combination of different waste materials to improve concrete properties is also reported by ALI et al. (2020), who used GF and industrial fly ash to mitigate the negative effects of incorporating recycled concrete aggregates as FA. Furthermore, the combination of multiple waste materials in concrete production contributes to environmental conservation and reduces production costs.

4.2.5 Utilization of recycled aggregate: brazilian regulations and application in Hong Kong

The Brazilian resolution (CONAMA) demonstrates the government's interest in increasing the recycling of CDW, similarly to Hong Kong where in 2002 the local government established a CDW recycling station with the aim of promoting the utilization of this material in different particle sizes (POON, CHAN, 2007).

The recycling of CDW is a global concern, and both Hong Kong and Brazil have public policies to encourage the use of CDW as aggregate in concrete, showing some points of convergence. Both countries classify concrete demolition waste as suitable for use as aggregate. However, there are differences in the resolutions, as the Brazilian resolution is more comprehensive and allows the utilization of various types of CDW as aggregate, while in Hong Kong only CDW derived from concrete is used. Another significant difference is the peculiar nature of CDW generation in Hong Kong, where the high population density in a small hilly area leads to large-scale demolition of old structures to make way for vertical buildings. This results in the production of a massive amount of construction waste, estimated at 20 million tonnes (POON, CHAN, 2007).

Researchers POON and CHAN (2007) conducted a case study on the construction of the Hong Kong Wetland Park, which consisted of two phases completed in 2000 and 2005, respectively. In the second phase, covering an area of 10,000 m², 13,000 m³ of concrete produced with CDW as aggregate were used. The researchers observed that the percentage of aggregate replacement with CDW varied depending on the concrete application. Due to the lack of experience in using CDW in concrete, the cement content needed to be increased to compensate for the higher water demand of the recycled aggregate.

After experimental analyses, the authors found that using CDW as both aggregate and mineral admixture simultaneously affects the strength and durability of the concrete. However, using CDW separately as aggregate or mineral admixture is feasible from both experimental and practical perspectives.

As mentioned earlier, the legislation in Hong Kong is less comprehensive than that of Brazil regarding the use of CDW as aggregate in concrete. The authors of this study proposed experimenting with mixtures using CDW derived from bricks and tiles, employing two mixing methods: conventional and dual. The conventional method involves mixing the materials for two minutes before adding water, while the dual method consists of adding half of the total volume of water, followed by the binder after one minute, and the remaining water added and mixed for another 90 seconds. Both methods were analyzed because the tested aggregates have high water absorption, which could influence future results.

The slump tests demonstrated that recycled concrete mixtures using the dual mixing method had an average slump of 33%. On the other hand, the density was hardly affected, and the compressive strength at 28 days was considerably enhanced by the dual mixing method. As a result, the authors suggest that it is feasible to expand the range of using CDW from other sources as aggregate. However, the authors caution against substitutions exceeding 20% of the mass of mineral admixture (POON, CHAN, 2007).

4.3 Data analysis

The authors of the described studies presented various scenarios for replacing conventional aggregates with recycled materials, and all of them obtained results regarding the proportions for concrete production. Table 1 shows the quantities, in mass, of each material required to produce one cubic meter of concrete (kg/m³), as used in the studies of the 5 analyzed works, along with the corresponding percentage indications of substitutions applied in each case.

Table 1: Proportions for producing $1m^3$ of concrete

PANDEY, KUMAR (2019)

PC	FA	CA	Water	MS	additives	RHA	Comments
406	663.87	1248.97	158	-	1.62	-	Control
405.1	663.87	1248.97	158	-	6.69	40.6	10% RHA
395.85	663.87	1248.97	158	10.15	3.65	-	2.5% MS
385.7	663.87	1248.97	158	20.3	4.26	-	5% MS
375.55	663.87	1248.97	158	30.38	4.86	-	7.5% MS
365.4	663.87	1248.97	158	40.6	5.28	-	10% MS
364.59	663.87	1248.97	158	20.3	6.90	20.3	5% MS | 5% RHA
355.25	663.87	1248.97	158	10.15	8.12	30.45	5% MS | 7.5% RHA
345.1	663.87	1248.97	158	40.6	9.74	20.3	10% MS | 5% RGA
334.95	663.87	1248.97	158	40.6	10.15	30.45	10% MS | 7.5% RHA

FRAZZAN, PERREIRA, AKASAKI (2016)

PC	FA	CA	Water	Rubber	Comments
342	884	1003	192	-	Control
360	772.6	1197.1	140	36	10% Rubber

XAVIER, BASSANI, MENDES (2016)

PC	FA	CA	Water	Silica	additives	EPS	Comments
416	737	1030	153	34	3	-	Control
416	737	1030	153	34	3	4.5	+ 100 g EPS
416	737	1030	153	34	3	9	+ 200 g EPS
416	737	1030	153	34	3	18	+ 400 g EPS

ZAID, et al. (2021)

PC	FA	CA	Water	SF	additives	CH	GF	Comments
320	460	895	175	-	2.4	-	-	Control
304	460	760,75	175	16	2.4	134.25	15.22	15% CH | 0.5% GF | 5% SF
288	460	625,5	175	32	2.4	268.5	28	30% CH | 1% GF | 10% SF
272	460	492,25	175	48	2.4	402.75	40.8	45% CH | 1.5% GF | 15% SF
256	460	358	175	64	2.4	537	51.2	60% CH | 2% GF | 20% SF

POON, CHAN (2007)

PC	FA	CA	Water	CDW (bricks)	CDW (roof tiles)	Comments
410	642	1043	225	-	-	Control
410	514	1043	225	128	-	20% CDW (bricks)
410	514	1043	225	-	128	20% RCC (roof tiles)

Source: Authors (2023)

Regarding the experiments, the analyzed articles tested various properties of concrete with recycled material, but the workability of the fresh mix and the compressive strength after 7 and 28 days were the tests common to all articles. These properties are critical for determining the feasibility of using recycled concrete in structural applications, as established by the standard NBR 8,953/2015. To be considered structural, the concrete must have a Slump between 100 and 160 mm for conventional placement methods and a minimum compressive strength of 20 MPa at 28 days of age (NBR 8.953, 2015). Table 2 summarizes the obtained values of workability and compressive strength in the five analyzed articles

Table 2: Values of slump test and mechanical compressive strength at 7 and 28 days of age

PANDEY, KUMAR (2019)			
Misture	**Slump (mm)**	**7 Days (Mpa)**	**28 Days (Mpa)**
Control	50	37.00	48.77
10% RHA	50	38.00	53.02
2,5% MS	50	38.80	54.08
5% MS	50	39.20	55.01
7,5% MS	50	32.80	51.07
10% MS	50	37.80	50.96
5% MS | 5% RHA	50	38.70	53.61
5% MS | 7,5% RHA	50	37.70	48.99
10% MS | 5% RHA	50	37.74	49.22
10% MS | 7,5% RHA	50	37.20	48.88
FRAZZAN, PERREIRA, AKASAKI (2016)			
Misture	**Slump (mm)**	**7 Days (Mpa)**	**28 Days (Mpa)**
Control	80	20.04	27.00
10% Rubber tire waste	110	20.94	28.37
XAVIER, BASSANI, MENDES (2016)			
Misture	**Slump (mm)**	**7 Days (Mpa)**	**28 Days (Mpa)**
Control	70	47.75	61.40
+100 g EPS	60	36.80	46.20
+ 200 g EPS	60	16.35	21.00
+ 400 g EPS	40	12.20	12.30
ZAID, et al. (2021)			
Misture	**Slump (mm)**	**7 Days (Mpa)**	**28 Days (Mpa)**
Control	55	10.00	21.00
15% CH | 0,5% GF | 5% SF	45	11.00	23.00
30% CH | 1% GF | 10% SF	40	15.00	24.00
45% CH | 1,5% GF | 15% SF	37	16.00	25.00
60% CH | 2% GF | 20% SF	35	9.00	19.00
POON, CHAN (2007)			
Misture	**Slump (mm)**	**7 Days (Mpa)**	**28 Days (Mpa)**
Control (ordinary misture process)	160	39.90	45.60
Controle (double misture)	95	53.80	61.40
20% CDW (brick | ordinary misture)	175	33.60	35.70
20% CDW (brick | double misture)	110	47.20	50.40
20% CDW (roof tile | ordinary misture)	150	30.50	43.20
20% CDW (roof tile | double misture)	120	45.50	55.30

Source: Authors (2023)

5 CONCLUSION

Based on the collected information, it can be concluded that concrete is widely used due to its strength, durability, ease of production, availability of raw materials, architectural versatility, and the absence of the need for skilled labor. However, large-scale concrete production generates unutilized waste, consumes finite natural resources, and contributes to climate change. The utilization of CDW as an aggregate is one of the most viable options, due it is already being encouraged by state laws and employed in large-scale projects. Substituting PC with recycled materials makes concrete less costly both in monetary terms and in terms of CO_2 emissions. On the other hand, substitutions in aggregates (CA and FA) tend to be appealing for recycling materials that were originally disposed of improperly, as these components constitute the majority of the concrete's volume. In summary, the use of recycled concrete for structural applications is a promising and sustainable alternative that contributes to a more environmentally friendly future.

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