Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN NO. 2320-5407

Article DOI:10.21474/IJAR01/15239
DOI URL: http://dx.doi.org/10.21474/IJAR01/15239

RESEARCH ARTICLE

EXPERIMENTAL STUDY OF PHYSICAL AND MECHANICAL PROPERTIES OF CONCRETE BY WASTE GLASS POWDER AS PARTIAL REPLACEMENT OF CEMENT

Etienne Malbila[1,2], Boris Djoko[3], AbdoulayeCompaore[1,4], David Toguyeni[5,6], Sié Kam[1,7] and Dieudonné Joseph Bathiebo[1,7]

1. Laboratoire d'Energies Thermiques Renouvelables, (LETRE),Université Joseph KI-ZERBO,Ouagadougou,Burkina Faso.
2. Université de Fada N' Gourma, Fada, Burkina Faso.
3. Institut Supérieur des Techniques Industrielles et Commerciales –Bangangté,Cameroun.
4. Institut de Recherche en Sciences Appliquées et Technologies, Ouagadougou,Burkina Faso.
5. Laboratoire de Physique et Chimie de l'Environnement(LPCE), Université Joseph KI-ZERBO,Ouagadougou,Burkina Faso.
6. Ecole Polytechnqiuede Ouagadougou(EPO),Burkina Faso.
7. Univerité Joseph KI-ZERBO (UJKZ),Burkina Faso.

……………………………………………………………………………………………………....

Manuscript Info

……………………….

Manuscript History
Received: 23 June 2022
Final Accepted: 25 July 2022
Published: August 2022

Key words:-
Formulation, Ecological Concrete, Waste Glass Powder, Cement, Compressive Strength, Workability

Abstract

………………………………………………………………

The environmental problem posed by non-biodegradable waste, such as non-reusable glass bottles, is becoming a major concern in view of the huge quantities in landfills in underdeveloped countries. Prospecting the valorization of waste glass in rural constructions constitutes a potential to reduce the use of natural materials in concrete industry. In this paper, the issues of environmental and ecological construction materials are addressed by the use of waste glass powder (Ø≤80µm) as replacement of cement in concrete. The aims of this project work is to usewaste glass powder in range of 10wt% to 20wt% as replacement of cement into concrete and concrete cylinder tested for its density, workability and compressive strength up to 45 days of age compared to those of conventional concrete. The obtain results indicate that the workability is increasing, the density and the compressive strength are decreasing up to 20wt% replacement ratio. Moreover, the compressive strength of WGP based concrete is lower than that of conventional concrete up to 28 days of age and becomes superior from 45 days age. The best obtain average values of workability and compressive strength are respectively 7.2cmand 30.25MPa up to 28 days of age for the case of BPV20. Thus, for its good pozzolanic characteristics and the influence on the properties of concrete, the glass powder obtained by basic grinding non-reusable glass debris can be used in the formulation of ecological concrete for common civil engineering applications.

……………………………………………………………………………………………………....

I. Introduction:-

The increase of waste glass can hurt the environment and could be very expensive and difficult to manage. Glass has become necessary and irreplaceable in daily human life due to its benefits like abrasion resistance, durability, and

Corresponding Author:- Etienne Malbila
Address:-Laboratoire d' Energies Thermiques Renouvelables,(LETRE),Université Joseph KI ZERBO,Ouagadougou, Burkina Faso.

availability in any form [1].Generally in shops, damage glass sheets and sheet glass cuttings are going to waste, which are not recycled at present and usually delivered to landfill for disposal [2]and this situation is too hard in undeveloped countries. Just like household waste, it is an issue of global concern [3]. The valorization of this waste glass as construction material represents a response to this problem [4] [5] [6]with several technological, economic and environmental advantages [7] [8] [9].The use of supplementary cementing materials (SCMs), which are silica-rich materials, is beneficial byimproving the fresh and hardened properties of concrete and the service life of structures [5]. They react with the portlandite released by the hydration of silicates in the presence of water to form a product similar to that obtained from Portland cement. Thus, it has become possible to reduce the amount of water in concrete and thus produce high-performance concrete [10]. Then, environmental problems have been taking into consideration as serious situation in the modern construction. Reusing and recycling the wastes consider as the only methods to reduce waste generated [11].

The inevitable surge in the production of waste materials inthe construction industry and deficiency in the management of construction waste materials is a result of the advancement in infrastructural development in the world today [12].To improve the physical, mechanical, and durability properties of concrete, several studies are being carried out using additions of natural origin or industrial residues. Their use provides the concrete with a denser matrix that will be more resistant to aggressive products [13]and reduces the consumption of natural resources as well as landfills and the emission of the Carbone dioxide gas in the production of cement which causes enormous damage to the environment[14][15]. Improving the quality of concrete aims to correct the pathologies of degradation and the impact on the environment and the living environment of the populations. However, with the pozzolanic properties of mixed glass finely ground, it can be possible to reuse this glass as a partial replacement of cement in the manufacture of concrete [16] [17]. These SCMs include fly ash, silica fume, blast furnace slag [18], marble powder [19] [20],and glass wool, glass powder, slag, etc. Several studies show that the different possibilities of the valorization of glass waste by substitution of aggregates and cement in concrete have been explored. Its effects on the physicochemical and mechanical characteristics were examined in the main research in this direction. The use of waste glass in concrete can offer an improvement in concrete performance and an asset for participation in sustainable development by reducing this waste [21]. However, composite material production is linked to the availability of inputs. Low water/binder ratios lead to lower permeability of concrete and additions of fines such as silica fume, clay, slag, and ash thus contributing to improved compactness through their granular fillers[22].The compressive strength of the resulting concrete is close to that of the control concrete, which shows that the use of glass as a filler is possible provided that the stability problem is addressed [4]. But Similarly,(L. Mechri et al, 2021) show that the presence of glass aggregates as a partial replacement for alluvial sand increases the performance of the mortar for an age of 28 days, in particular for the case of cement mortar with 20wt% of glass aggregates [23].

The actual context is dominated by an increase in solid waste (such as plastic, glass, etc.)and the insufficiency of recycling facilities.Development of local alternative supplementary-cementitious materials (ASCM) such as ground mixed-waste glass is demanded especially when other ASCM are not locally available or costly [24]. The production of cement as a hydraulic binder involves extensive energy absorption [25] and is responsible for 4 to 8% of global CO_2 emissions and 50% in the construction sector [26]. While the construction sector has a high demand for natural resources, and due to the high cost of natural raw materials [27], alternatives solutions are being explored by the construction industry and researchers. It is especially important to conduct research that reveals new opportunities for the use of waste in the creation of new construction materials [27].Since, several research into the influence of glass waste as coarse aggregates or replacement of cement in concrete mixing on other characteristics is studied. The use of recycled glass helps in energy and environment saving and its significant contribution is tothe construction filed [2]Therefore, this study focuses on the use of waste glass in the development of new concrete for civil engineering structures. This secondary resource is a potential solution for significant contribution to the construction sector. The difference between glass waste and other solid waste is the possibility of their repeated recycling without loss of operational properties, as well as extremely slow decomposition in natural conditions [28]However, the addition of high amounts of glass (>30 wt%) into the ceramic bodies is undesirable due to its adverse action on the physical properties of the product [29].

The behaviour of supplementary cementing materials in concrete is different from that of Portland cement alone. The incorporation of SCMs in place of cement has effects on hydration kinetics, hardening, strength, and durability [30] [31][32].

The incorporation of glass powder affects the mechanical properties and durability of concrete. As reported by (R. Chaïd et al. 2015), the contribution of glass powder to the binding activity of cement results mainly from two effects: a physicochemical and microstructural effect and a chemical effect [13]. It can show several types of behaviour, mainly according to its granularity: a coarse granularity tends to provoke an alkali-reaction phenomenon generating disorders, whereas a fine glass develops a beneficial action identifiable with a pozzolanic reaction [33].

As reported by (Ayesha Siddika et al, 2021) [34] the chemical and mineralogical composition, and particle size of WG, mix proportion, activation, and curing condition of concrete are the most important parameters that affect the dissolution behaviour of WG and chemical reactivity between WG and other elements in concrete. The behaviour of WG help to produce durable concrete against shrinkage, chemical attack, freeze-thaw action, electrical and thermal insulation properties. The optimum replacement volume of binders or natural aggregates and particle size of WG need to be selected carefully to minimize the possible alkali-silica reaction [35].Several research works concluded that the optimum percentage of waste glass as replacement of cement is at 10%replacement of cement [36] [37], 15wt% replacement of cement [38] [39] [40] and at 20wt% by [41] [42][43]. Experiments have shown that when fine natural aggregate is replaced with glass waste, the strength of concrete decreases due to the lack of adhesion between the glass-cement stone particles. Substitution of 30wt% cement by a powder with a maximum particle diameter of 38 µm resulted in a pozzolanic activity and [25]ideal replacement level as it exhibits quite comparable strengths, better workability, and higher resistance to chloride-ion penetration compared to the control mix and provides maximum tensile splitting strength at 28 days [44]. Furthermore, an extensive experimental program was carried out including pozzolanic activity, setting time, soundness, specific gravity, chemical analyses, laser particle size distribution, X-ray diffraction, and scanning electron microscopy (SEM) on WGP and resistance to alkali-silica reaction (ASR), chloride ion penetration resistance, absorption by capillarity, accelerated carbonation and external sulphate resistance on mortar containing WGP [45].The compressive strength of concrete depends on the quality of the hydrated calcium (C-S-H) developed. The addition of a cementitious material as a partial replacement for cement will react with the portlandite, resulting in the formation of a new C-S-H which will fill more cavities, thus decreasing the porosity and improving the compressive strength [10].The microstructure of the waste glass concrete resulting that more voids created after 20% replacement of waste glass which affects the compressive strength and split tensile strength of the concrete thus make the optimum replacement percentage is 20% replacement [46]. In addition, temperature variation is another parameter influencing the behaviour of the ice powder; in fact, according to (M. Mirzahosseini and Kyle A.Riding, 2014) the elevated temperatures cause glass powder to exhibit significant pozzolanic reaction, even at early ages [47]. In the previous study, the condition of obtaining of glass powder are not analysed enough. So, the method of crushing is an unknown parameter and its influence on the properties of WGP based concrete. Therefore, the main aim of the present study is to process non-recycled glass bottles into powder obtained by crushing by physical and manual effortfor incorporation as replacement cement at 10wt%, 15wt% and 20wt% into the concrete mix design and to evaluate the workability and mechanical properties.

II. Material and Methods:-

This study is performed in three main stages. These are the determination of the components of hydraulic concrete and its formulation, then the preparation of concrete specimens, and finally the characterization of physical and mechanical properties. The following paragraphs describe the raw materials used, the characterization of the inputs, the formulation study, and the characterization of the formulated specimens.

2.1 Raw material

Concrete is the most versatile material used as construction material all over the world [15] and replace progressively the local construction material in undeveloped countries.Concrete is a cementitious composite material consisting of a mixture of well-defined proportions of cement, aggregates, water, and possibly additives. The mixing water must be clean and free of dirt.

2.1.1 Cement

The choice of the type of cement depends on the compressive strength class (**σ'c**) the criteria of use (speed of setting and hardening, the heat of hydration, etc.). The true class of cement is the average compressive strength obtained at 28 days on standardized mortar specimens. The cement used in this study is type CEM II/B-S 42.5R and $\sigma'_c = 47\text{Mpa}$.

2.1.2 Waste Glass Powder

TheWGP is a white alternative SCM. Its high amorphous silica content SiO2 gives it pozzolanic properties by combining with lime to produce another hydrate [33] [48].Glass waste consisting mainly of bottles were collected, sorted, and crushed. Their density of Waste glass is$\gamma_s = 1.535$ and the particle sizes of the derived waste glass powder are less than 80µm**.**The table 1 below give the chemical properties of cementitious materials such a cement and glass powder:

Table 1:- Chemical composition (% in mass) of cement and glass powder [49]

N°	Characteristics	Cement	Glass powder
01	SiO2	17.50	70,90
02	Al2O3	4.36	1.93
03	Fe2O3	3.10	0.40
04	CaO	60.40	13.30
05	MgO	1.70	0.18
06	K2O	0.58	0.33
07	SO3	2.50	0.06
	Na2O	-	12.40
08	PAF	10	0.50
10	Density	3,10	2,59

2.1.3 Aggregates

The aggregates used in concrete production need to allow the creation of a granular skeleton with a minimum of voids. Consequently, aggregates of all sizes must be used so that the smallest elements fill the voids left by the largest. Within the framework of this study, we have the granular class: 0/25, divided into 0/5, 5/15, 15/25, and presented in figure 4 below. The table 2 below summary the physical characteristics of aggregates used in the mixes:

Table 2:- The physical characteristics of the aggregate.

N°	Measured Parameters		Result	Required standard
01	The equivalent of sand (ES)		96.75% (to visual); 98.24% (to the piston)	ES>60
02	Coefficient of Flatness (A)		Gravel 5/15, A=18.49 Gravel 15/25, A=21.50	A<35
03	Hardness test (Los Angeles)		LA= 11.8 et 12.1	LA<40
04	Cleanliness test		P=1.66%	P≤2%
05	Density	Sand 0/5	$\gamma_s = 2.613$	-
		Gravel 5/15	$\gamma_s = 2.924$	
		Gravel 15/25	$\gamma_s = 2.905$	

The determined parameters indicate that the selected aggregates meet the prescribed limits for use in the manufacture of concrete.

2.2 Characterizationof the concrete components

The quality of the concrete is partly linked to the quality of its components and their propositions in the mix. Thus, the study of the behaviour of concrete in the fresh and hardened states requires particular knowledge of the influence of its different components [50]. The workability of concrete decreased with the substitution of WG and RCA while mechanical performance improved up to a certain limit and then decreased due to lack of workability [51]. It is therefore necessary to identify these constituents before formulation. For this characterization, the tests are summarized in Figure 1 below.

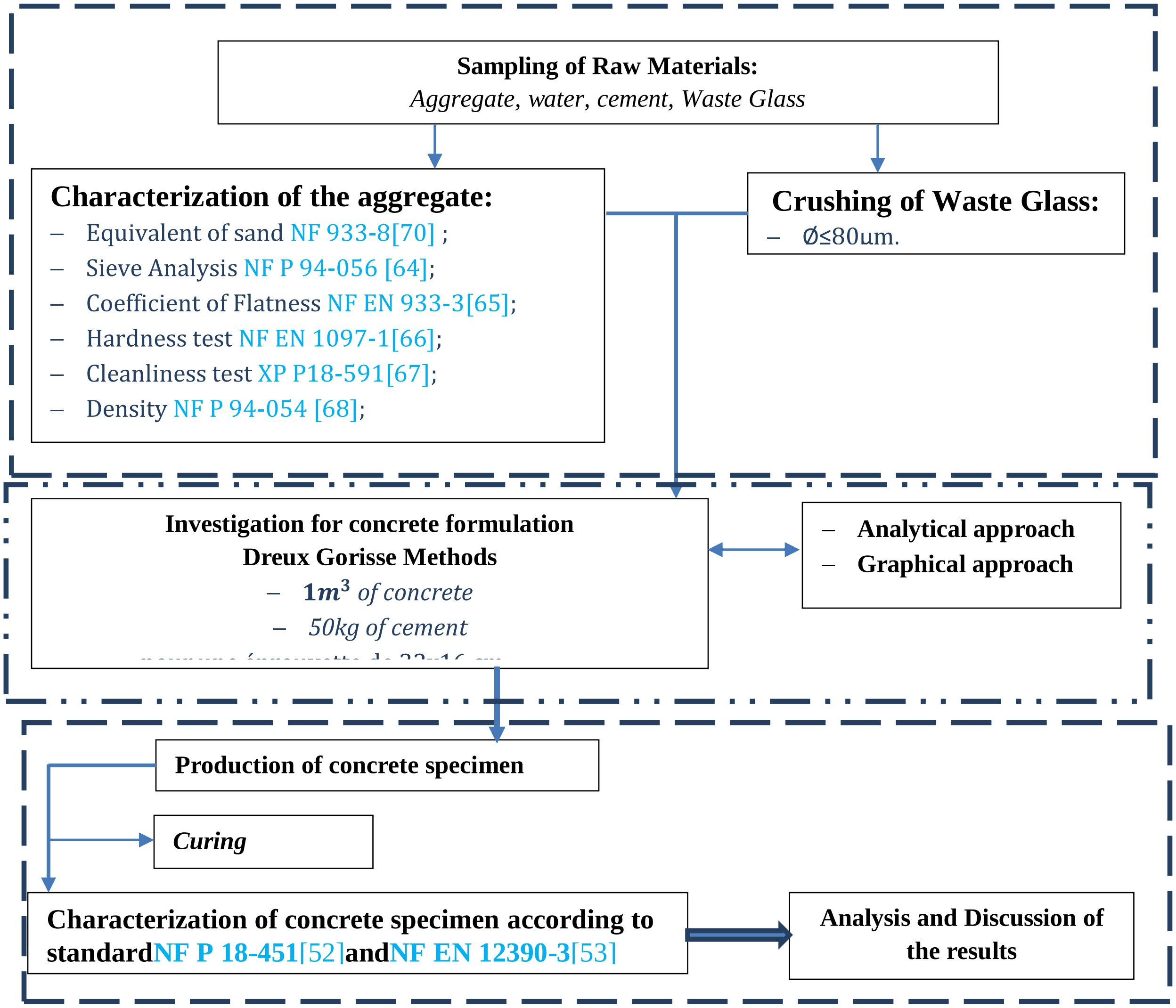

Figure 1:- Study framework.

2.3 Composition of concrete mixes

Table 3:- Composition of concrete mixes.

N°	Component	BR	BPV10	BPV15	BPV20	BR-15
1	Cement	16.50%	14.85%	14.02%	13.20%	14.02%
2	Sand (0/5)	25.60%	25.60%	25.60%	25.60%	25.60%
3	Gravel (5/15)	6.51%	6.51%	6.51%	6.51%	6.51%
4	Gravel (15/25)	42.70%	42.70%	42.70%	42.70%	42.70%
5	Water	8.69%	8.69%	8.69%	8.69%	8.69%
6	WGP		1.65%	2.47%	3.30%	0%

Five types of hydraulic concrete were mixed, including three types of concrete with substitutions of cement by glass powder at proportions of 10%, 15%, and 20%. Table 3 shows the results of the formulation with the quantities of the cementitious components of the concrete.

Table 4 : Summary of the formulation of the concrete

N°	Type of the concrete	BR	BPV10 (10% WGP)	BPV15 (15% WGP)	BPV20 (20% WGP)	BR-15 (0%WGP)
1	% de WGP	0	10%	15%	20%	0%

2	% Cement	100	90%	85%	80%	85%
3	Volume WGP (ρ_s=1,33)	0	28.04	42.06	56.09	-
4	Volume cement (ρ_s=3,1)	120.3	108.27	102.25	96.24	102.25
5	Weight of cement (kg/m^3)	372.93	335.7	317.05	298.4	317.05
6	Weight of WGP (kg/m^3)	0%	37.30	55.95	74.60	-

Note: BPV10 means concrete with 10% of Waste Glass Powder as replacement of cement.

Table 4 present the type of concrete mixes with the proportion of cementations materials. The content of cement in the BPV15 and RC-15 concrete is identical and the comparison of these two types of the mix aims to see the impact of the glass waste powder on the properties of the concrete.

2.4 Experimental Parameters and Tests

The experimental investigation was carried out in two stages: the first stage consisted of the formulation of different types of concrete mixes; the second stage consisted of subjecting prepared concrete samples to different curing regimes. A mix design based on the mass of the concrete was used in both stages (see Table 3) with constant w/c equal to 0.52. Each mix consisted of 6 cylinders, tested at each curing age.Fresh and mechanical properties like workability and compressive strength were evaluated in the first and second stages.

The workability of the fresh concrete is determined by the slump cone test by the standard NFP18-451 [52].

The mechanical characterization concerns the determination of the compressive strength of a concrete specimen. The principle of the test is governed by standardNF EN 12390-3 [53].The test procedure recommends the preparation (surfacing of the specimens) andthe positioning of the specimens in a mechanical press and then applying the load in a continuous manner and without shocks until the specimen breaks. With the mechanical press used, the loading ratio is kept constant throughout the test and is equal to 0.5 MPa/s, with a tolerance of +/- 0.20 MPa/s.

2.5 Specimen and curing

Concrete cylinders of dimensions 16 cm (diameter) and 32 cm (height) were prepared by standard NF EN 12390-3 [53]. Cylindricalmoulds were filled in two approximate equal layers and compaction was done by rodding 25 strokes per layer. Thirty specimens of concrete cylinders were cured in laboratory ambient conditions, and then de-moulded, identified, and subjected to the respective curing conditions until the testing age.

III. Result

3.1 Fresh concrete consistency

The characterization of the fresh concrete focused on the consistency of the mix with the determination of the slump and the density of the composite. Then, the workability and the density of the mixes are given in Figures2, 3, and 4below.

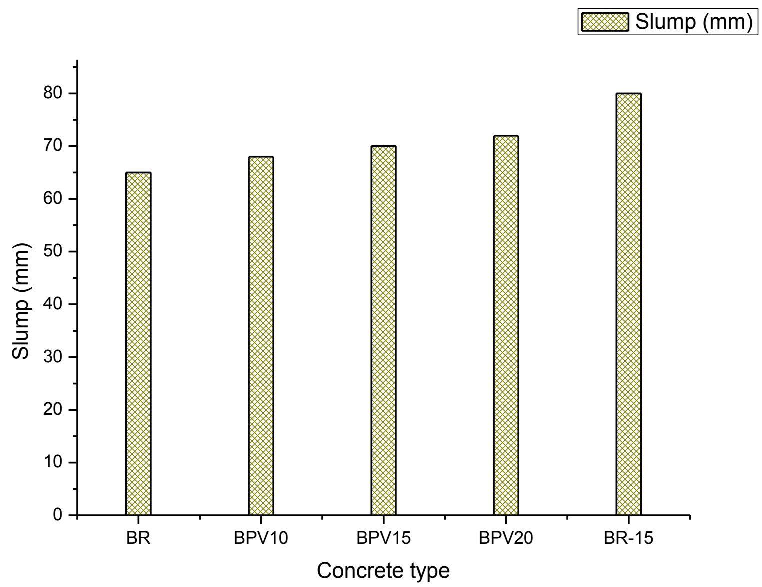

Figure 2:- Workability of the mixes.

From graph in figure 2, BPV20 and BR-15 show highest results. In terms of consistency, the conventional concrete BR has a lower slump than concretes at 10% to 20% ofWGP replacements. It shows that the 20% of waste glass powder of replacement give the most increase workability of the fresh concrete. The amount of workability is proportional to the ratio of substitution of cement by glass powder and increase with the increase of WGP percentage used in concrete, whereas the density is inversely proportional. The more glass powder is added, the more the slump increases, this is because glass is impermeableandthe smooth surface of the waste glass that absorb less water during mixing process [46].

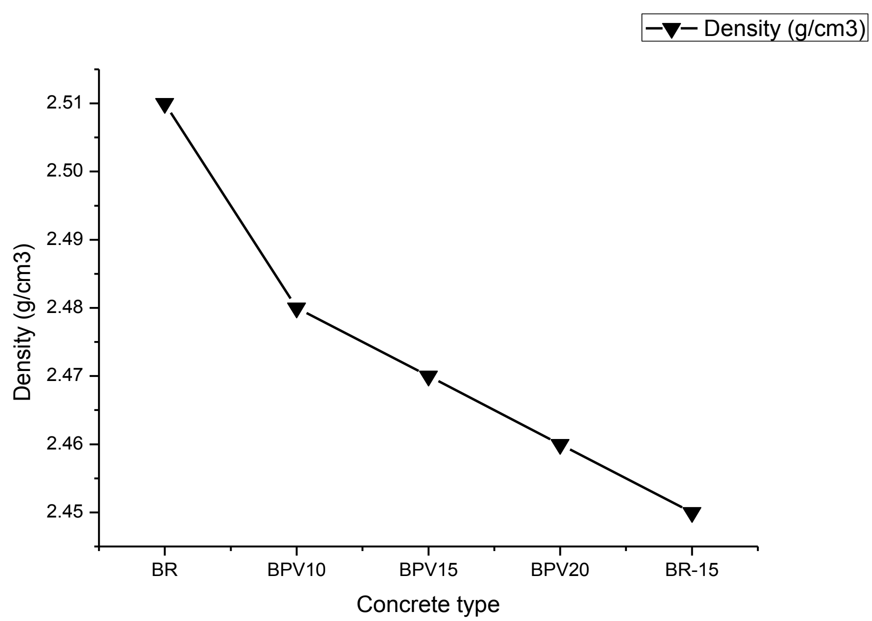

Figure 3:- Density of the concrete specimen.

Figure 3shows that the conventional reference concrete has the highest density than the other concrete mixes. The value of density decreases with the increase of WGP percentage used in concrete. The more glass powder is added, the more the slump decreases. This is becausethe cement has higher specific gravity than that of the glass powder.

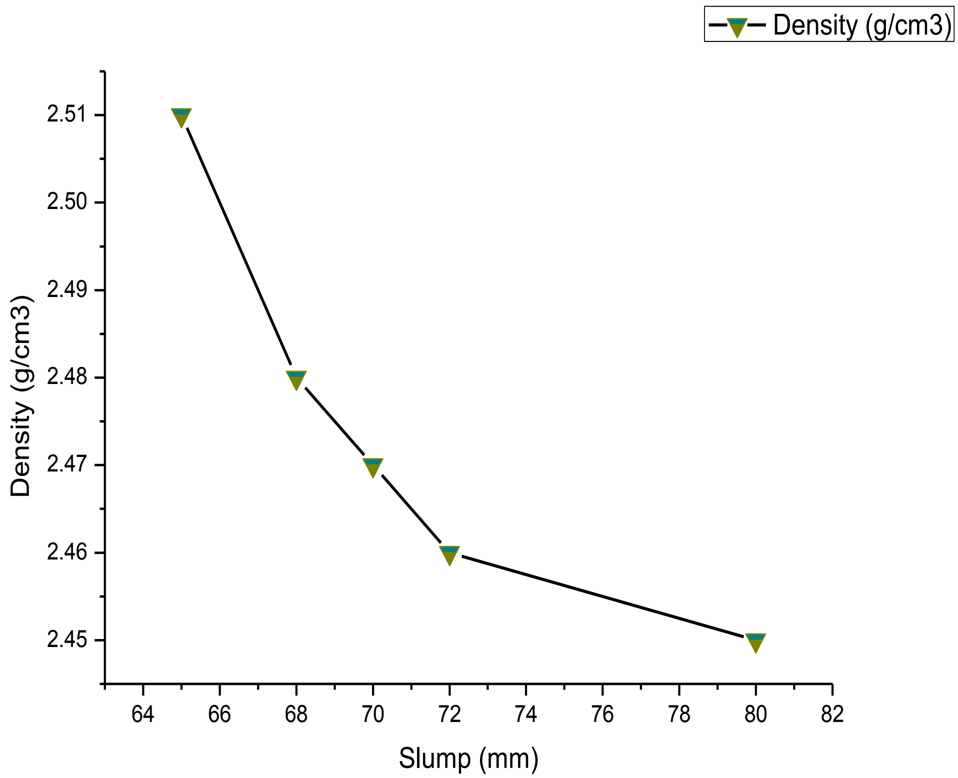

Figure 4:- Workability as a function of the density of the mixes.

Figure 4above shows the evolution of the consistency of concrete as a function of density. It is noted that the workability is inversely proportional to the density of the formulated concrete.

3.2 Compressive Strength of Specimen

The mechanical strength is expressed by the power of the concrete to resist destruction due to the stresses of the different compressive loads [14]. The test was carried out conforming to standard NF EN 12390-3, to obtain compressive strength at 7days, 14 days, 28 days and 45 days. The specimens were tested using mechanical compression machine by loading continuously at 0.5Mpa/s ±0.20 Mpa and without shocks until its breaks. The variation of the compressive strength is studied as a function of the substitution ratio of cement by glass powder and also as a function of the curing time of the samples. The results obtained after compression of the different concrete specimens are listed in figures 9 to 13 below and represent average values of the crushed specimens according to the age of the concrete.

3.2.1 Compressive Strength of the concrete at 7 days, 14 days, and 28 days

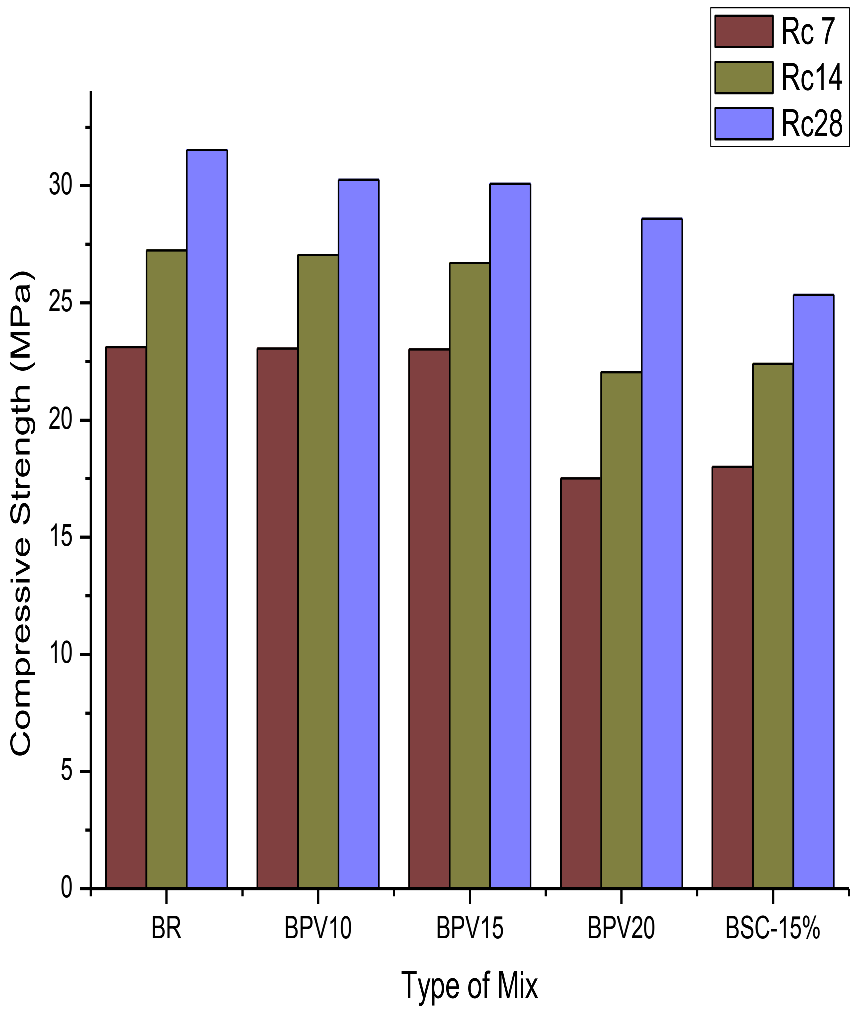

Figure 5:- Compressive Strength at 7days, 14 daysand 28days.

Concrete was projected to achieve approximately 100% of its strength in 28 days [46]. From result in figure 5, for concrete mixes, all results have obtained a minimum compressive strength of 25 Mpa at 28 days age. The graph in figure5, indicates that the compressive strength is increasing for each sample up to 28 days ages. The compressive strength of Reference conventional concrete is high among other mixes. When the ratio of waste glass powder increases in the mixes, it was identified that compressive strength is decreasing up to 28 days' age. The important gapof compressive strength is observed between the BPV20 compared to the BR, with average ration of 24.28%, 19.09% and 9.26% respectively at 7 days, 14 days and 28 days. However, the reduction in the quantity of cement reduces the compressive strength, as can be seen with BR-15, with a difference of 22.11%, 17.77%, and 19.61% respectively at 7, 14, and 28 days of age.

3.2.2 Compressive Strength of the concrete at 45 days

The results obtained with the compression tests of the different concrete specimens at 45 days of age are presented in the following figure 6.

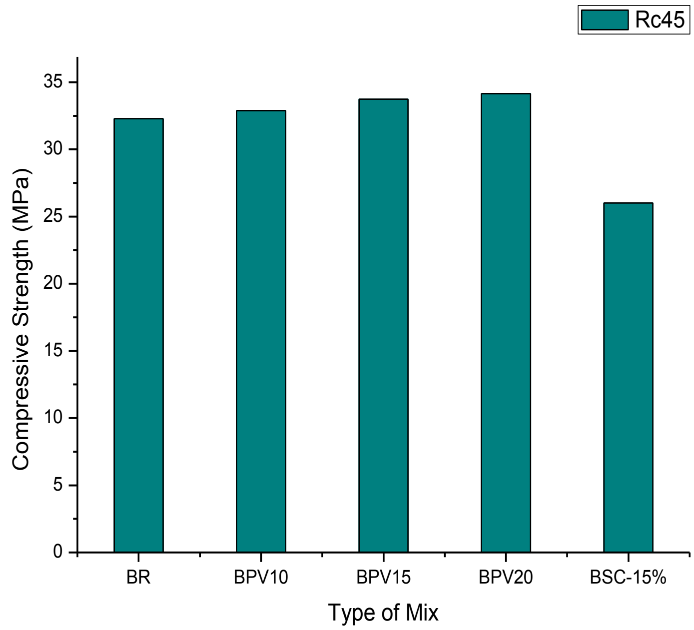

Figure 6:- Compressive Strength at 45 days.

The diagrams in Figures 6 and 7show that the compressive strength is increasing among all mixes at 45 days of age and the compressive strength of conventional reference concrete get lesser value thanWGP based concrete. The gap in compressive strength is 1.86%,4.49%, and 5.76% respectively for BPV10, BPV15, and BPV20 compared to BR. Furthermore, it can be seen that the compressive strength of BPVs is proportional to the substitution ratio of cement by glass powder ($R_{CBPV\,20}$>$R_{CBPV\,15}$>$R_{CBPV\,10}$).

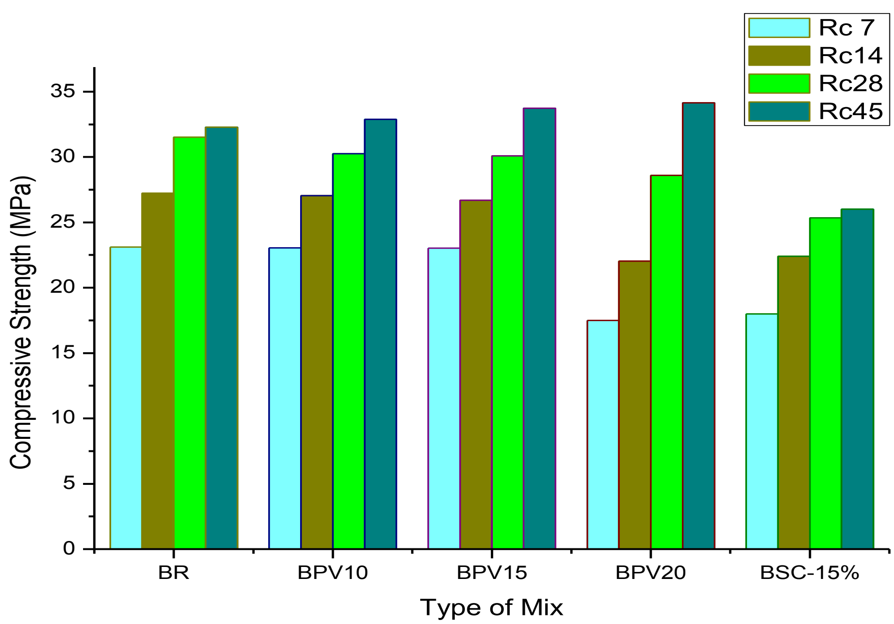

Figure 7:- Compressive strength at 7, 14, 28 and 45 days age.

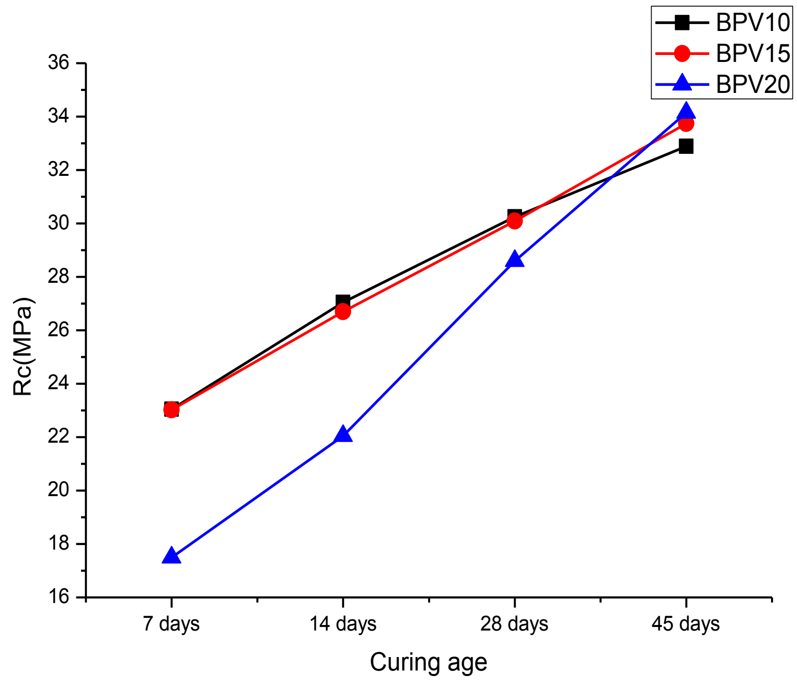

Figure 8:- Compressive strength development over time with Glass Powder.

The graph in figure 8, indicates that the compressive strength of BPV20 concrete increases earlier than that of BPV15 and BPV10 concrete after 28 days. This is the effect of the Waste Glass Powder in the concrete and this difference is explained by the replacement ratio.

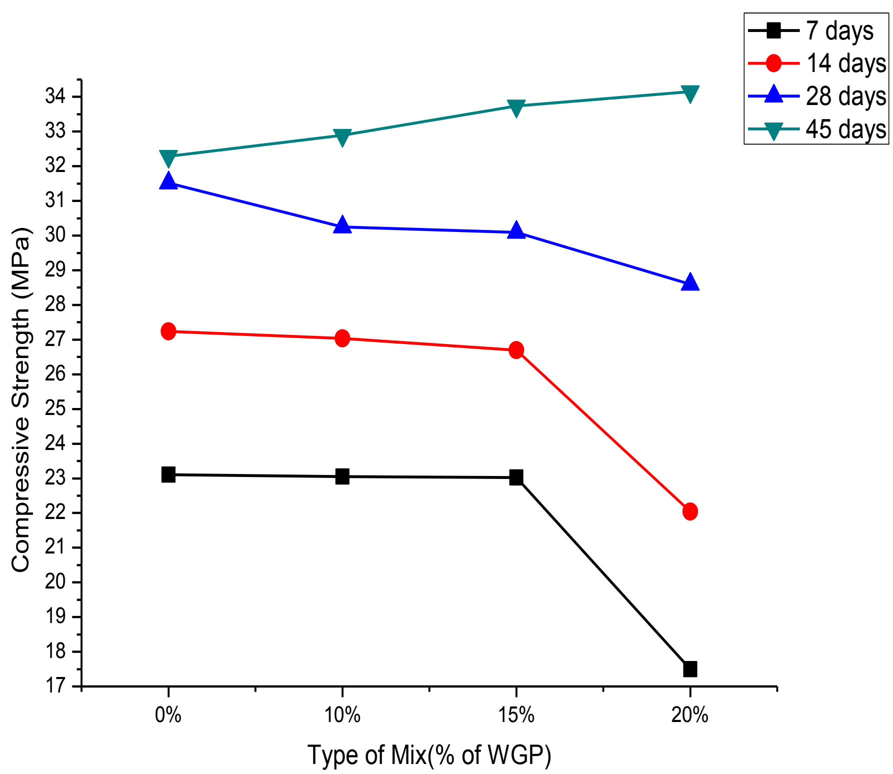

Figure 9:- Compressive strength as a function of the content of Glass Powder.

Figures 7 to 9show the variation in compressive strength with the waste glass powder incorporation ratio and the curing time of the concrete specimens. Therefore, it appears that the compressive strengths of BPV10 and BPV15 concrete are higher than those of BPV20 at a young age (i.e. 7 to 28 days) and the trend is reversed when the concrete is over 28 days old and the observation is confirmed at 45 days of age.

IV. Discussion:-

4.1 Summary of the main finding

According to the above-mentioned characterization results, all raw material used into the formulated concrete are of suitable quality.In terms of physical properties, it is noted that the slump is proportional to the increase in the replacement ratio of cement by glass powder, while the density decreases. In fact,the density should be decreased gradually at increasing of waste glass powder replaced as cement into the concrete. The density of the fresh concrete mixes decreases up to 2% at 20wt% replacement ratio. With increasing of WGP into the concrete, the workability should be increased gradually as compared to reference conventional concrete.This can be explained by the fact that the denser the concrete, the lower its consistency and workability. This finding is by the results by [9][54]. This is due to the reduction in the amount of cement into the concrete. The less cement leg is available to provide the binding effect, and therefore the adhesion between the aggregates is not strong. Indeed, SiO2 reacts with portlandite (which is a constituent of the hydration of calcium silicates in the cement. Alternatively, it is a product of the hydration of quicklime released by the hydration of silicates in the presence of water, giving rise to new C-S-H (calcium silicate hydrate) similar to that obtained by Portland cement. This substance effectively fills the voids and gives rise to a dense microstructure of the concrete. The waste glass powder then offers resistance against the expansion forces caused by the penetration of sulphates and sulphate ions into the concrete [10].

For compressive strengths, there is a negative correlation (-0.69 to -0.96) with the substitution ratio of glass powder as replacement of cement up to 28 days of age and a positive correlation (+0.97) at 45 days of age. The compressive strengths of WGP based concrete become highest after 28 days of age compared to reference conventional concrete and are attested by the values obtained at 45 days of age In general, glass powder affects the compressive strengths of concrete. According to the results obtained from the crushing tests, we note that the glass powder concretes resistless at young ages (7 and 14 days) and 28 days of age compared to the reference concrete, this is explained by the fact that the glass powder plays a role of pore filler at young ages, and makes the structure of the concrete denser. This was also observed by [55]. However (M. Mejdi, 2019) reported that for substitution ratio up to 20wtwt%, the mechanicals properties are notednotably affected [18]. No significant differences were observed in compressive strength of concrete with the presence of RGS in concrete, while an average reduction of 16% occurred when 20% of the Portland cement was replaced by PGP [56]In other applications, the substitution of Zogbodomey clay with 5% Benin wood ash or 20% ground glass leads to fired blocks with increased three-point bending tensile strength and compressive strengths comparable to blocks without addition [57].The significant increase in compressive strength of BPV compared to BR is observed after 28 days of age and the test results obtained at 45 days indicate an increase in strength of the concrete with glass powder compared to the reference concrete in the range of 1.86% to 5.76%. This trend was observed at 90 days by (Zeghichiet al. 2012 et B. Arab et al, 2017) [22].This is due to the pozzolanic reaction of the glass which takes time to start. These results are in agreement with previous studies where it is noted that the strengths of ordinary concrete incorporating glass powder develop over time [55], [56][58], [59].And the high SiO2 silica content of the glass powder gives it pozzolanic properties that increase with the glass powder content. Then (Y. Wang et al., 2020) conclude that the replacement ratio played a dominant role in strength at both the early or long-term age [60],[61].

So, from the evolution of the compressive strength of the formulated concretes, it can be said that the characteristic compressive strength of 34.5 MPa will be reached faster after 45 days with BPV20. Then, the workability and compressive strength are increasing up to 20wt%. From another point of view, it can be envisaged that increasing the substitution ratio of cement by glass waste powder to 25-30% will accelerate the growth of the characteristic compressive strength and reduce the time to reach it. Because, at 30% to 40% replacement level the workability is increasing and the compressive strength goes to decreasing, and Split tensilestrength is slightly decreasing as compared to normal concrete [62].

Another interesting finding is the comparison of BPV15 and BR-15 concrete. At all age of curing, the compressive strength of BPV15 is higher than that of BR-15. This illustrates that the strength of concrete is strongly related to the cement dosage and that the substitution of cement by glass powder is interesting and applicable. In this way, the quantity of cement can be reduced by up to 15% with glass powder, while maintaining the compressive strength.

The results show that the replacement of cement by WGP influences the compressive strength of the concrete. Moreover, this compressive strength is also inversely proportional to the WGP content in the concrete. The Waste Glass Powder (WGP) influences the formulation of the concrete, based on the comparison oftheconcretemixes with reductionof 15wt% of cement (BR-15) and the concrete mixes with 15wt% WGP as replacement of cement (BPV15). Therefore, the use of waste glass powder intothe concrete is an important issue in the preservation of the environment, because the replacement of cement into the concrete for the reduction of CO_2 global emission. The availability, the cost and transportation of certain supplementary cementing materials (SCMs) have an environmental and economic impact [49] [63]and the use of local alternative resources as waste glass may be a potential solution to consider in undeveloped country.

4.2 Strength and limitations

The study focused on the effect of WGP as partial replacement of cement by 10wt%, 15wt% and 20wt% on the workability and compressive strength of the concrete mixes. These two parameters are essential in the use of concrete in civil engineering applications. However, the study could not measure the evolution of density with the curing period and also the tensile/bending strength and durability of these glass powder concrete specimens. Furthermore, the process of obtaining glass powder is still laborious and it is important to identify better crushing approaches.

4.3 Implication on practice and research

This investigation addresses a current problem in developing countries wherewaste management is still in its early stages and is not regulated. These initial investigations give satisfactory results and open up avenues for the exploitation of glass waste (bottles) in powder form as a cement additive. Thus, it shows that the substitution ratio makes it possible to obtain levels of consistency and compressive strength according to the specifications. These types of concrete, especially with the 20% ratio, can be used in the realization of concretes and reinforced concretes for residential buildings, and paving stones.

In perspective, the research may include:

- Characterizing the tensile and/or flexural strengths of formulated concrete specimens;
- Characterizing the chemical properties of waste glass powder;
- Evaluation of the durability of the concrete formulated at 10% to 20% replacement ratio of cement by WGP;
- Determining the substitution ratio to optimize the consistency and mechanical properties and obtain the characteristic compressive strength at 28 days of age;
- Evaluation of the comparative grey energy of the glass powder concretes and the normal concrete to measure the level of durability.

V. Conclusion:-

Based on the investigation and experimental results, the followings conclusions were drawn:

- With increasing of WGP into the concrete, the workability should be increased gradually as compared to reference conventional concrete. So, the incorporated waste glass powder allows an increase in workability and the highest value of 7.2cm (i.e. 10.77%) is obtained at 20% replacement ratio;
- The density should be decreased gradually at increasing of waste glass powder replaced as cement into the concrete. the density of fresh concretemixesdecreasesup to 2% at 20wt% replacement ratio;
- The compressive strength of reference normal concrete is highest at a young age, i.e., up to 28 days of age, compared to the reference conventional concrete;
- The compressive strengths of WGPbased concrete become highest after 28 days of age compared to reference conventional concrete and are attested by the values obtained at 45 days of age. The concrete with 20wt% WGP offers the highest strength by 5.76% more than the reference conventional concrete.
- There is an opportunity for the use of WGP as replacement of cement into the concrete for the reduction of CO_2 global emission.

This study highlighted the influence of WGP on the concrete's physical and mechanical characteristics.To do this, it is important to:

- identify the components of the concrete according to the standard and technical specifications in use;
- apply the concrete formulation method, based on the specifications;
- respect the experimental protocols for the characterization of concrete and cementitious materials.

Author's contribution

All authors have read and agreed to the published version of the manuscript."

Acknowledgements:-

The authors thank the BUF 01 project supported by ISP, Uppsala University, Sweden.

Conflicts of Interest

The authors declare no conflict of interest.

References:-

[1] C. M. Yun, M. R. Rahman, K. K. Kuok, A. P. Sze Chai, A. B. Shi Ding and M. K. Bin Bakri, "Glass Waste as Coarse Aggregate Filler Replacement in Concrete," in Waste Materials in Advanced Sustainable Concrete, Springer nature, 2022, pp. 25-44.

[2] V. S. Arivalagan and S. Sethuraman, "Experimental study on the mechanical properties of concrete by partial replacement of glass powder as fine aggregate: An environmental friendly approach," Materials Today: Proceedings, vol. 45, no. 2, 2020.

[3] K. KRAUSOVÁ, "Vers de nouvelles matrices minérales pour l'immobilisation et la valorisation des déchets ultimes de l'incinération des déchets ménagers," Paris, 2013.

[4] I. KHAZAZ and A. DOUMI, "Valorisation des déchets de verre dans le domaine de matériaux de construction," Bejaia, 2018.

[5] A. H. Eddine, "Contribution à l'étude de la valorisation des déchets industriels dans l'amélioration des performances du béton," 2021.

[6] M. BEHIM and T. ALI BOUCEITA, "Valorisation du verre à bouteille comme addition fine dans les bétons autoplaçants," Déchets Sciences et Techniques, vol. 65, pp. 20-28, Novembre 2013.

[7] A. Zidol, "Optimisation de la finesse de la poudre de verre dans les systèmes cimentaires binaires ," Library and Archives Canada, Sherbrooke, 2009.

[8] B. Samir, D. Farid, B. Mohamed and G. Mohamed, "Valorisation et Recyclage des Déchets Plastiques dans le Béton," MATEC Web of Conferences, pp. 1-4, 2014.

[9] S. Meriem, "Etude expérimentale d'un béton à base de déchets de verre," 2019.

[10] S. CHEKIREB, "Valorisation de la poudre de verre dans le béton autoplaçant," Sherbrooke (Québec) Canada, 2015.

[11] H. Dr S Mahmoud, N. Mohammed Tarrad and A.-H. Dr A Ismail, "Beneficial role of glass wastes in concrete_A review," Journal of Engineering and Sustainable Development, vol. 22, no. 2, pp. 136-144, 2018.

[12] O. Amadise S, T. John A and D. Enyeru U, "Enhancement of Concrete Compressive Strength bythe Synergy of Blocks, Bricks, and Glass Powder asMineral Admixtures in the Production of Concrete," International Research Journal of Advanced Engineering and Science, vol. 5, no. 3, pp. 218-221, 2020.

[13] R. Chaïd, H. Zeroub and D. Rangeard, "Concrete durability indicators with glass powder addition in marine environment," AlgérieEquipement, no. 56, pp. 17-25, 2015.

[14] M. Mekki, N. Abdelghani and Z. Salim, "Effect of crushed glass aggregates on the physico-mechanical properties of micro-concrete.," Lebanese Science Journal, vol. 19, no. 2, pp. 210-228, August 2018.

[15] V. N. Rao, B. Suresh, R. V. Suryaprakash and B. H. S. Kalyan, "Investigation on Mechanical Properties of Concrete by Partial Replacement of Cement with Waste Glass Powder and Fly Ash," nternational Journal of Mechanical and Production Engineering Research and Developmen, vol. 10, no. 3, pp. 11883-11888, 2020.

[16] J. DESCHAMPS, "Evaluation critique du Principe d'économie circulaire en Boucle ouverte via deux exemples de valorisation du verre mixte," Sherbrooke (Québec) Canada, 2018.

[17] K. Jain, S. Akodiya, Y. Panwar, V. Sharma, S. Jain and R. Shekhawat, "To study the effect of the partial replacement of cement by using glass powder & fly ash in concrete," International Journal of Civil Engineering, vol. 3, no. 5, 2016.

[18] M. MEJDI, "Compréhension des mécanismes d'hydratation des ciments composés incorporant de la poudre de verre ou des cendres de boues d'épuration calcinées," Paris, 2019.

[19] B. RACHID, "Etude de bétons à hautes performances à base de poudre de marbre et de centres," 2013.

[20] M. Tennich, M. Ben Ouezdou and A. Kallel, Effets des déchets de marbre et de carrelage sur les propriétés à l'état durci du béton autoplaçant, 2015.

[21] H. Abdelli, L. Mokrani, S. Kennouche and J. Aguiar, "Utilization of waste glass in the improvement of concrete performance: A mini review," Waste Management Research, vol. 38, no. 11, pp. 1204-1213, Novembre 2020.
[22] B. Arab, R. Mehaddene and Y. Bouchnab, "Substitution du ciment CPA par la poudre de verre dans les mortiers à hautes performances," Déchets Sciences et Techniques, no. 75, pp. 1-8, 2017.
[23] L. Mechri, S. Saggaï, D. Benlarbi-Oulhaci and L. Benharoune, "Use of glass aggregates as a partial sand replacement: effects on mortar performance," Journal of Fundamental and Applied Sciences, vol. 13, no. 1, pp. 436-452, 2021.
[24] F. Omran, Ahmed, E. Morin, D, D. Harbeca and A. Tagnit-Hamoua, "Long-term performance of glass-powder concrete in large-scale field applications," Construction and Building Materials, vol. 135, pp. 43-58, 2017.
[25] Z. Kalakada, J.-H. Doh and S. Chowdhury, "Glass powder as replacement of cement for concrete – an investigative study," European Journal of Environmental and Civil Engineering, December 2019.
[26] Norme européenne NF EN 197-1, « Ciment-Partie 1 : Composition, spécifications et critères de conformité des ciments courants », Éditée et diffusée par l'Association Française de Normalisation (AFNOR),, Paris: Tour Europe 92049, Février 2001.
[27] G. Mammadova, N. Jafarova and M. Sadigova, "Preparation of concrete based on glass waste," March 2022.
[28] I. Mikulionok, "State and Prospects of handling glass(Review)," Energy Technologies & Resource Saving, vol. 1, pp. 33-50, 2022.
[29] O. Njindam, D. Njoya, J. Mache, M. Mouafon, A. Messan and D. Njopwouo, "Effect of glass powder on the technological properties and microstructure of clay mixture for porcelain stoneware tiles manufacture," Construction and Building Materials, no. 170, p. 512–519, 2018.
[30] M. BOULIFA and A. DEBABI, "Utilisation de poudre de verre dans le mortier," 2017.
[31] B. F. AYGÜN, "An overview of the impact of using glass powder on mechanical,durability properties in self-compacting concrete," Journal of Sustainable Construction Materials and Technologies, vol. 6, no. 3, pp. 116-123, September 2021.
[32] A. BOUCHIKHI, "Optimisation de la valorisation des déchets de verre et de sédiments dans des liants recomposés : Activation Formulation de mortiers-Stabilisation physico-chimique," 2020.
[33] A. AYADI, Technologie du verre_Edition OPU, 2004.
[34] A. Siddika, A. Hajimohammadi, W. Ferdous and V. Sahajwalla, "Roles of Waste Glass and the Effect of Process Parameters on the Properties of Sustainable Cement and Geopolymer Concrete—A State-of-the-Art Review," Polymers (Bassel), vol. 13, no. 22, 2021.
[35] A. Siddika, A. Hajimohammadi, M. A. A. Mamun, R. Alyousef and W. Ferdous, "Waste Glass in Cement and Geopolymer Concretes: A Review on Durability and Challenges," Polymers (Basel), vol. 13, no. 13, 2021.
[36] R. Vandhiyan, R. Ramkumar and R. Ramya, "Experimental study on replacement of cement by glass powder.," International Journal of Engineering Research and Technology, vol. 2, p. 234–238., 2013.
[37] G. Gahoi and R. Kansal, "Waste glass powder as a partial replacement of PPC," International Journal of Science and Research, vol. 5, p. 1414–1418., 2016.
[38] M. Meena, J. Gupta and B. Nagar, "Performance of concrete by using powder- an experimental study.," International Research Journal of Engineering and Technology, vol. 5, p. 840–844., 2018.
[39] A. Karde, M. Bagwan, M. Gowda, R. Kudale and P. Jagtap, "To study properties of concrete using waste glass powder replacement to cement.," International Journal for Scientific Research and Development, vol. 6, p. 992–996, 2018.
[40] F. Khan, M. Fahad, K. Shahzada, H. Alam and N. Ali, "Utilization of waste glass powder as a partial replacement of cement in concrete.," International Journal of Advanced Structures and Geotechnical Engineering, vol. 4, p. 181–185., 2015.
[41] R. Sakale, S. Jain and S. Singh, "Experimental investigation on strength of glass powder replacement by cement in concrete with different dosages.," International Journal of Science Technology and Engineering, vol. 2, pp. 76-86, 2016.
[42] K. Prudhvi, K. Saiprasad, K. Reddy, K. Manoj Kumar and D. Vinay, "Laboratory study on compressive strength of concrete with glass powder as partial replacement of cement.," Journal of Emerging Technologies and Innovative Research, vol. 3, p. 272–277., 2016.
[43] V. Kumar and H. Sood, "Effect of waste glass powder in concrete by partial replacement of cement.," International Journal of Civil Engineering, vol. 4, pp. 13-22, 2017.
[44] S. Rahman and M. Uddin, "Experimental investigation of concrete with glass powder as partial replacement of cement.," Civil Engineering and Architecture, vol. 6, p. 149–154., 2018.

[45] A. Mafalda, J. Matos and S. Coutinho, “Durability of mortar using waste glass powder as cement replacement,” Construction and Building Materials, vol. 36, pp. 205-215, Novembre 2012.
[46] N. Mokhtar and J. NurulAtikah, “A Review on the Performance of Waste Glass as Partial Replacement of Fine Aggregate,” IOP Conference Series: Materials Science and Engineering, vol. 1200 012011, pp. 1-7, 2021.
[47] M. Mirzahosseini and K. A. Riding, “Effect of curing temperature and glass type on the pozzolanic reactivity of glass powder,” Cement and Concrete Research, vol. 58, pp. 103-111, 2014.
[48] M. CHABI and B. LAMALI, “Valorisation de la poudre de verre dans un béton ordinaire destiné pour la précontrainte,” 2017.
[49] A. H. Eddine, “Contribution à l’étude de la valorisation des déchets industriels dans l’amélioration des performances du béton,” 2021.
[50] M. AYAD and Y. BARKA, “Modélisation des béons ordinaires par des plans d'expériences,” Tlemcen, 2013.
[51] J. Ahmad, R. Martínez-García, J. de-Prado-Gil, K. Irshad, M. A. El-Shorbagy, R. Fediuk and N. I. Vatin, “Concrete with Partial Substitution of Waste Glass and Recycled Concrete Aggregate,” Materials (Basel), vol. 15, no. 2, 2022.
[52] NF P 18-451: Bétons-Exécution des structures_Règles spécifiques pour les BFUP, 2018.
[53] NF EN 12390-3: Essais pour béton durci-Partie 3: resistance à la compression des éprouvettes, 2019.
[54] A. H. Elaqra, M. A. AbouHaloub and R. N. Rustom, “Effect of new mixing method of glass powder as cement replacement on mechanical behavior of concrete,” Construction and Building Materials, vol. 203, pp. 75-82, 10 April 2019.
[55] A. Shayan and A. Xu, “Performance of glass powder as a pozzolanic material in concrete: A field trial on concrete slabs,” Cement and Concrete Research, vol. 36, no. 3, pp. 457-468, March 2006.
[56] B. Taha and G. Nounu, “Properties of concrete contains mixed colour waste recycled glass as sand and cement replacement,” Construction and Building Materials, vol. 22, no. 5, pp. 713-720, May 2008.
[57] G. S. G. MILOHIN, “Valorisation des rebuts de bouteilles en verre et des cendres de bois dans la fabrication des briques en argile cuite,” 2019.
[58] N. S. N. Neithalath, “Influence of a fine glass powder on cement hydration: Comparison to fly ash and modeling the degree of hydration,” Cement and Concrete Research, vol. 38, no. 4, pp. 429-436, April 2008.
[59] M. Kamali and A. Ghahremaninezhad, “Effect of glass powders on the mechanical and durability properties of cementitious materials,” Construction and Building Materials, vol. 98, pp. 407- 416, 2015.
[60] Y. Wang, Y. Cao, P. Zhang and Y. Ma, “Effective Utilization of Waste Glass as Cementitious Powder and Construction Sand in Mortar,” Materials, vol. 13, no. 707, 2020.
[61] A. Zidol, M. T. Tognonvi and A. Tagnit-Hamou, “Effect of Glass Powder on Concrete Sustainability,” New Journal of Glass and Ceramics, vol. 7, no. 2, pp. 34-47, 30 April 2017.
[62] B. Kavyateja, P. N. Reddy and U. Mohan, “Study of strength characteristics of crushed glass used as fine aggregate in concrete,” nternational Journal of Research in Engineering and Technology, vol. 5, no. 2, pp. 157-160, 2016.
[63] M. I. Malik, M. Bashir, S. Ahmad, T. Tariq and U. Chowdhary, “Study of Concrete Involving Use of Waste Glass as Partial Replacement of Fine Aggregates,” IOSR Journal of Engineering, vol. 3, no. 7, pp. 8-13, 2013.
[64] NF P 94-056, Sols: reconnaissance et essais-Analyses granulométrique-Méthode par tamisage à sec après lavage, 1996.
[65] NF EN 933-3, Essais pour déterminer les caractéristiques géométriques des granulats-Partie 3: Détermination de la forme des granulats-Coefficient d'applatissement, 2012.
[66] NF EN 1097-1, Essais pour déterminer les caractéristiques mécaniques et physiques des granulats-Partie 1: Détermination de la résistance à l'usure (micro-deval), 2011.
[67] XP P18-591, Granulats-Détermination de la propreté superficielle, 1990.
[68] NF P 94-054_Sols: reconnaissance et essais: Détermination de la masse volumique des particules solides des sols-Méthode du Pycnomètre à eau, 1991.
[69] NF EN 206/CN: Bétons structuraux de bâtiments et d'ouvrages de Génie civil, 2014.
[70] NF 933-8: Essais pour détermner les caractéristiques géométriques des granulats-Partie 8: Evaluation des fines-Equivalent de sable, 2012.

Highlight

The manual method of collecting, processing and crashing waste glass up to Ø80µm can be used in concrete mixes.
The consistency of the formulated concretes was characterized through the measurement of workability and density.
The mechanical strength of the reference conventional concrete specimens and concretes with the glass powder as

replacement of cement were characterized at 7 days, 14 days, 28 days and 45 days. The experimental results of fresh and hardened concrete, such us workability, density and compressive strength were presented andanalysed. The effect of WGP as partial replacement of cement into concrete on the properties of the concrete was investigated and showed the best result at 20wt% replacement ratio. This study presents an introduction to the use of waste glass powder in cementitious materials for civil engineering applications in developing countries.

Nomenclature

Acronyms and abbreviations

ASCM	Alternative Supplementary Cementitious Materials
ASR	resistance to alkali-silica reaction,
BR	Reference Concrete
CSH	Silicate of Hydrated Calcium
LA	Coefficient of Los Angeles
MPa	MegaPascal
BPV	Waste Glass Powder based concrete
BPV10,BPV15,BPV20	*Concrete with the replacement rate of cementby the Waste Glass Powder*
PGP	Pozzolanic Glass Powder
RCA	Recycled Concrete Aggregate
RGS	Recycled Glass Sand
SCMs	Supplementary cementing materials
SEM	scanning electron microscopy
WG	Waste-Glass
WGP	Waste Glass Powder

Symbols

wt%	Weight percentage
σ’$_{28}$	Mean compressive strength of concrete at 28 days in MPa
σ’$_c$	Cement strength class
C/E	The ratio of cement and water in concrete
G’	Coefficient of the particle size distribution of aggregate
Copt	Optimal cement content
Cmin	Minimum cement content
Dmax	Maximal size of aggregate
kg	kilogram
L	litre
m^3	Cubic meters
%S	Sable ratio in concrete
%g and %G	Gravel ratio in mix concrete
γ	The compactness of the concrete
$\gamma_0, \gamma_1, \gamma_2, \gamma_3$	Adjustments for aggregates form and density and cement content,
Vc	Volume of cement
Vs	Volume of sand
V_G	Volume of gravel
V_m	The volume of the solid components of concrete
V_{tg}	Total Volume of granulates
ρ_c	Bulk density of cement (g/cm3)
ρ_s	Bulk density of sand
ρ_g, ρ_G	Bulk density of gravel
Ms	Mass of sand
Mg, M_G	Mass of gravel
n	Number of a cement sack for the production of the concrete