Incorporation of glass from used photovoltaic solar modules into the concrete matrix of construction as a partial replacement of cement in Burkina Faso

ABSTRACT

Several wastes can be recycled and used in the field of civil engineering. The incorporation of glass waste into the concrete matrix allows us to sustain and preserve natural resources. The aim of this study is to efficiently recycle glass waste from photovoltaic solar modules, for use in concrete as a partial replacement for cement. We obtained in this work different results depending on the amount of glass added to replace the cement. The tests began on the 7th day of concrete production and we waited until the twenty-eighth of concrete production, which is 10/29/2022, for the final compressions to be carried out. The control concrete P1 gives a value of 23.88MPa or 95.52% of 25MPa, the glass-enhanced concrete 10% of the weight of cement P2 presents a value of 24.66MPa or 99.04% of 25MPa, for the glass-enhanced concrete 15% of the weight of P3 cement we obtain 20.36MPa or 81.44% of 25MPa, Glass-enhanced concrete 20% of the weight of P4 cement gives a value of 17.88MPa or 71.52% of 25 MPA. P2 presents a higher result than that of the control concrete (24.66MPa > 19.49 MPa). We also note that the value of P2 is very close to the normal fixed during the formulation of the concrete. Therefore, we can say that the compression result of the 28th day of the improved concrete of the glass 10% of the P2 cement is acceptable compared to the others (P1, P3, P4). As the PV solar module has several components such as resin, Tedlar, solar cells and aluminum, it is not excluded to make a hypothesis on the chemical impact of these in the glass powder. This requires full-fledged research on the properties of used glass in order to improve the values of the compressive strength and to draw a conclusion on the incorporation of glass into the concrete matrix in Burkina Faso. The use of waste glass in concrete will contribute to sustainable development. The incorporation of glass waste into the concrete matrix allows us to reduce associated carbon dioxide emissions and lower cement production costs.

Keywords: Cement, Glass powder, Used solar modules, Incorporation, Concrete.

1. INTRODUCTION

Glass is one of the commonly used materials in all walks of life. Technically, after specific screening and cleaning, the glass waste collected can be remelted to manufacture new glass products. However, due to their multiple types, colors and contaminations, glass waste is often buried in a landfill or simply stored somewhere. The safe disposal of the huge amount of glass waste has become a serious environmental concern in many countries [1]. Glass is widely used due to its unique properties such as high transparency, safety and durability. However, the manufacture of glass products has resulted in the generation of massive amounts of waste glass, which constitutes a significant portion of solid waste in many countries. Since glass waste is not biodegradable, it is inappropriate to dispose of it in landfills and potentially cause serious environmental pollution. As a result, great controversy surrounds the disposal of waste glass. Currently, “recycling” waste glass is a generally accepted and widespread practice, as it conserves resources and contributes to sustainability. Recent research has demonstrated the potential for using waste glass in concrete, especially in the construction industry. The rapid development of infrastructure around the world has increased the demand for construction materials [2]. The concept of utilizing waste for construction applications has a long and successful history, which includes fly ash, slag and silica fume. These once problematic wastes buried in landfills are now considered valuable products that can be used to improve certain properties of concrete. One waste that continues to face challenges as a component of concrete is bottle glass. The advantages of developing alternative or additional cementing materials as a partial replacement for cement powder are described by researchers [3], who divide them into ecological, economic and technical categories. Ecological or environmental benefits of alternative materials include diversion of non-recycled waste materials from landfills to useful applications, reduction of negative effects of cement powder production i.e. consumption of non-renewable natural resources, reduction of consumption energy for the production of cement and the corresponding emission of greenhouse gases. The current research trend indicates that waste glass can be considered as a suitable construction material due to its flexibility. The recycling of waste glass for the development of cementitious and geopolymer concretes as sustainable building materials has recently attracted increasing attention for the construction industry. There are many previous studies on the effects of waste glass used in powder, sand or cullet form depending on the different sizes on the fresh and mechanical properties of concrete. However, few studies have been conducted on the durability performance of glass concrete waste [4]. Many review articles have concluded that waste glass qualifies as additives in cementitious composites [5]. Researchers have examined the application of solid waste including recycled glass, but they have not studied the specific mechanical properties and durability of cementitious materials filled with waste glass. Several researchers have summarized the key performance of concrete with waste glass as a replacement for cement or aggregate, while many other properties relating to long-term performance have not been discussed [1]. The global volume of glass sent to landfill is estimated at around 200 million tons per year. Research on waste glass as a building material began in the 1960s [6], concrete is the most commonly used building material and for the most part is produced from non-renewable natural resources and energy-intensive processes that emit greenhouse gases. There is an opportunity to improve the sustainability of this industry by further exploring the use of alternative materials. As an aggregate, waste glass bottles have faced specific challenges including bonding, and concrete strength degradation. The summary of some researchers showed workability, mechanical strengths, chloride and water permeability of concrete incorporating silica fume and waste glass. In addition to mechanical properties, some research has examined water absorption, shrinkage, chloride and sulfate attack of glass-filled cementitious materials [1]. In addition, researchers [7] practically applied concrete containing 80 kg/m3 of glass powder as a binder for the construction of interior and exterior slabs, sidewalks and walls. After several years of construction, concrete samples drilled from structural elements.

On the other hand, hundreds of thousands of tons of glass are stored and landfilled around the world every year, posing a serious threat to the environment. Since glass is a non-biodegradable material, it takes a million years to degrade naturally. Therefore, nowadays, the recycling of waste glass has become a major concern for the scientific community. In this regard, a significant number of research works have studied the use of waste glass in cementitious systems. Glass has been shown in the literature to be used in mortar and concrete in six possible ways, such as raw material for cement production, partial replacement of cement, partial or total replacement of fine aggregates, partial replacement combined with cement and fine aggregates.

Research has been done on the mechanical properties and durability of concrete with waste glass and shows that many investigations have reported conflicting results due to different glass types, fineness, content and preparation procedures. The long-term durability of concrete containing waste glass remains a great concern, which severely limits its wide practical application. The discrepancies actually prevent the recycling of waste glass for the production of cementitious and geopolymeric concrete [4]. In view of the reforms undertaken in the sector in Burkina Faso, the use of photovoltaic solar equipment has taken on a significant proportion. Thus, from 2010 to 2018, 83,340 tons of photovoltaic panels were imported, compared to 26,698 tons of imported batteries (according to a study carried out by ANEREE in 2019) [8]. We observe a very rapid evolution illustrating the fact that the use of photovoltaic panels will be very important in the future. In addition, the limited lifespan of equipment, the use of unsuitable means of transport and the flooding of the Burkinabè market with equipment of dubious quality will contribute to an increased production of waste". The challenge for reusing used modules is finding a large and sustained market for hundreds of peak gigawatts of decommissioned modules per year, and the big challenge for component mining is the sheer number of structures involved in the process of treatment of materials from worn panels [9].

According to ANEREE data on the quantities of waste expected in the years to come, that of glass will reach its peak in 2042 with a value of more than 3000 tons. Therefore, it is more than necessary to have an effective glass recycling procedure that takes into account environmental and health impacts. The establishment of a local glass recycling structure will help fight unemployment and generate revenue for the state. Our work will consist in a first place to make the formulation of the concrete in second place we will carry out the various types of the concretes and in third place will carry out the tests of compressions on the specimens containing the concretes.

2. FORMULATION OF THE CONCRETE

2.1 Constituents of concrete

Concrete is a composite material made up of coarse and fine aggregates (gravel or crushed stone, sand), cement and water. The mixture between cement and water forms a paste which hardens. Hydrated cement paste and sand make up the mortar. Its role is to bind the aggregates to form a solid conglomerate. The formulation of this concrete was determined using the DREUX-GORISSE method.

- Cement: It is a hydraulic binder which comes in the form of a fine mineral powder that hydrates in the presence of water. It forms a paste that sets and hardens gradually in air or in water. It is the fundamental constituent of concrete since it allows the transformation of a mixture without cohesion into a solid body.

A single type of concrete mix was used for the manufacture of the different specimens to be studied. The cement used is a CPJ-CEMII/42.5R type cement produced by a Burkinabe company.

- Aggregates: They constitute the skeleton of the concrete. They must be chemically inert with respect to cement, water and air. It is possible to produce concrete aggregates which can be of detrital (mainly alluvial), sedimentary, metamorphic or eruptive origin.
- Water: In general, the mixing water must have the properties of drinking water. It is excluded to use seawater which contains approximately 30g/l of sodium chloride, for the manufacture of reinforced or prestressed concrete. The mixing water used is tap water, it is very clean water.
- Glass treatment: the glass cover of the module is removed and crushed using the mortar made from the aluminum of the module. At the end of the process, homogeneous glass fragments are obtained. The glass fragments obtained will be used on site in the construction.

In our case, we had the glass crushed and transformed using a local machine used by gold miners on September 06, 2022; the operation took 02 hours (i.e. from 3 p.m. to 5 p.m.). It is composed of two essential parts; one which is a diesel engine and another which receives the energy sent by the engine to crush the glass. Figure 1 shows the glass grains and glass powder.

Fig. 1.Pictures showing glass grains and glass powder

2.2 Theoretical dosage of concretes

The theoretical dosage of control concrete was determined by the DREUX-GORISSE method.
crushed sand cement.

Table 1.Photo Theoretical dosage in dry materials

Theoretical dosage in dry materials				
Dosage Constituents	For one cubic meter of fresh concrete		Volume for a bag of cement (l)	Quantity in (kg) per batch
	weight (kg)	volumetric		
Control concrete				
Crushed 15/25	763.8	492.8	64.8	38.19
Crushed 15/25	336.2	215.5	28.4	28.4
Sand	663.2	414.5	54.5	33.16
Cement	380.0	-	50 kg	19
Total water	206.8	206.8	27.2	10.34

Glass concrete 10% of the weight of cement				
Crushed 15/25	763.8	492.8	64.8	38.19
Crushed 15/25	336.2	215.5	28.4	28.4
Sand	663.2	414.5	54.5	33.16
Cement	380.0	-	50 kg	17.10
Glass	-	-	-	1.9
Total water	206.8	206,8	27.2	10.34
Glass concrete 15% of the weight of cement				
Crushed 15/25	763.8	492.8	64.8	38.19
Crushed 15/25	336.2	215.5	28.4	28.4
Sand	663.2	414.5	54.5	33.16
Cement	380.0	-	50 kg	16.15
Glass	-	-	-	2.85
Total water	206.8	206.8	27.2	10.34
Glass concrete 20% of the weight of cement				
Crushed 15/25	763.8	492.8	64.8	38.19
Crushed 15/25	336.2	215.5	28.4	28.4
Sand	663.2	414.5	54.5	33.16
Cement	380.0	-	50 kg	15.20
Glass	-	-	-	3.80
Total water	206.8	206.8	27.2	10.34

2.3 Method of making the concrete

After measuring the mass needed to make the trigger, all the aggregates are poured into a cement mixer. It is made up of an asynchronous machine that supplies the rotary mechanical force to the drum to mix the concrete. The cylindrical molds (16/32) provided for the concrete specimens were prepared,

Following the determination of the proportions of each component, the selected mixing sequence was as follows:

- Humidify all the material to be used;
- Introduce l and the glass sand, the crushed aggregates 5/15 and 15/25 into the mixer;
- Start the mixer to homogenize the mixture for 30s;
- Leave the mixer running and gradually add the pre-wetting water and mix it for 30s;
- Add the cement and the glass powder, then mix everything for 30s;
- Pour the remaining water gradually and leave to mix for 60s;
- Immediately carry out slump tests on fresh concrete.
- Fill the molds with test specimens by simple pouring (manual stitching).

The installation was carried out in the various molds intended for the samples corresponding to the scheduled tests. The concretes were subjected to vibrations by manual pricking to better compact the concrete and eliminate the air bubbles inside. The demolding was carried out after 24 hours.

3. EXPERIMENTATION

After the theoretical formulation of the concrete production method, we carried out the Gachet on October 01, 2022.

- **Quantity measurements by mixing aggregates, cement and glass powder**

In accordance with the concrete formulation data in Table 1, the amounts of the various constituent elements of the concrete must be carefully measured. For this we used the results of the concrete formulation and the tools necessary for the work. The tools we used include an electronic scale with a capacity of 30kg and containers to store the measured quantity. All masses above the range of the scale have been divided in order to have a good precision and not to destroy the scale.

Figures 2, 3, 4, 5 and 6 show the measurements of the mass of sand, cement and crushed aggregates 5/15 and 15/25.

Fig. 2.Measurement of the mass of sand **Fig. 3.Measurement of the mass of crushed aggregate**

Fig. 4.Measurement of the mass of glass **Fig. 5.Measurement of the mass of cement**

Fig. 6.Mixing glass powder and cement

- **Obtaining a homogeneous fresh concrete after mixing in the mixer**

Figure 7 shows the image of the concrete in the mixer and in the wheelbarrow to move on to the next step which is the measurement of the slump.

Fig.7.Images of the formed concrete

- **Sag measurement**

This step consists in determining the slump according to the volume of water predetermined during the formulation of the concrete. After having obtained a homogeneous fresh concrete, the results of the subsidence by mixing are as follows:

• 5 cm with a volume of 11.34 dm^3 of water for conventional concrete
• 5.6o cm with a volume of 9 dm^3 of water for concrete with 10% glass
• 5 cm with a volume of 9 dm^3 of water for concrete with 15% glass
• 3.90 cm with a volume of 9 dm^3 of water for concrete with 20% glass

Figure 8 presents photos of sag measurements

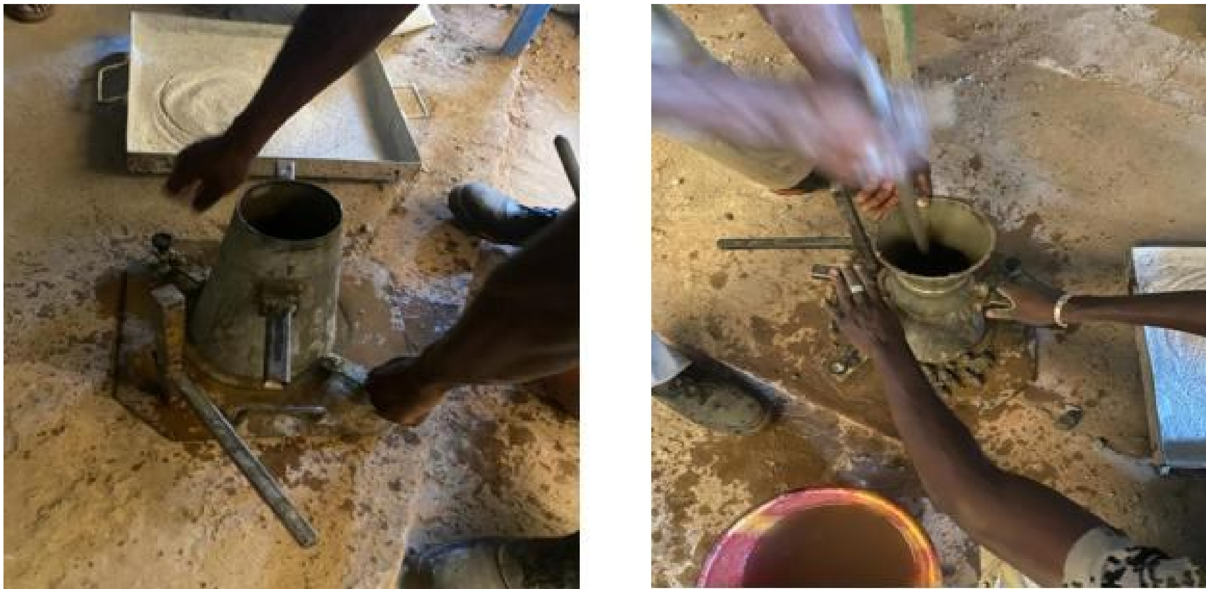

Fig. 8.Photos of sag measurements

- **Molding**

After having had a good slump, the fresh concrete is ready for casting. Cylindrical molds 32cm high and 16cm in diameter will be used. The mold is first lubricated with engine oil to facilitate demolding after 24 hours. Each mold well filled with concrete was poked 25 times with the manual poking rod. Put excess concrete on top of the mold before starting poking. Prick the top layer, through its entire thickness, so that the stem penetrates slightly into the underlying layer. Each trigger fills a series of six (06) molds then numbered. Figure 9 shows the photos of the casting of the concrete in the specimens.

Fig. 9.Photo of the casting

- **Compression resistance tests (NF EN 12390-3)**

The compression tests on the 7th and 28th day were carried out on 24 specimens, using the “Controlab” type compression machine (figure below). The 18 concrete specimens are incorporated with powdered glass waste and the

remaining 6 specimens are those of the control concrete. The crushing speed used is 0.5 KN/s in order to have the values of maximum resistance and maximum force. Then, we deduced the best variant to use for the rest of our experimentation. The resistances are measured on cylindrical or prismatic specimens whose molds have characteristics defined by standard NFP 18-400 for which the most frequently used molds are cylindrical molds.
Figure 10 shows the photo of the compression machine

Fig. 10. Photo of the compression machine

4. RESULTS AND DISCUSSION

In accordance with standard NF P 18-406, the compression test is carried out on cylindrical specimens whose ends have been ground beforehand. Indeed, if the specimens were placed as they are on the platens of the press, one would not be assured of the flatness of the surfaces in contact and of their perpendicularity to the generatrices of the specimen. Grinding therefore consists in making these surfaces flat and perpendicular to the generatrices of the specimen. To achieve this result, two methods can be used: surfacing with sulfur and rectification by machining the ends. Sulfur surfacing is described in standard NF P 18-416. It consists of providing each end of the specimen with a sulfur-based wafer that meets the two requirements: flatness and perpendicularity to the generatrices. Flatness is ensured as follows: the sulfur mixture, brought to a temperature of 125°C ±5°C, is liquefied and poured onto a plate whose bottom has been ground (figure 6.5.1). Perpendicularity is obtained by means of a guide device which keeps the generatrices of the specimen perpendicular to the rectified bottom of the mold. The specimen held by the guide device is lowered onto the liquefied sulphur. When, after cooling, the sulfur has solidified, the specimen (to which the sulfur cake then adheres) is separated from the plate and the second end is surfaced. For specimens whose compressive strength does not exceed 50 MPa, surfacing can be done with a mixture of 60% (by mass) flower of sulfur and 40% fine sand with a grain size of less than 0.5 mm. Beyond that, and up to 80 MPa, a sulfur mixture specially designed for High Performance Concretes must be used. Figure 18 shows photos of the compression process.
The effect of adding glass has been extensively discussed in several works. However, the mechanisms of reactions occurring as a function of grain size have been neglected.
We have seen that in general, in this work the different results depending on the amount of glass added to replace the cement. The compression of the seventh day presents the following results: for the concrete witness P1 we record 19,49MPa is 77,96% of the value fixed for the formulation which is 25MPa. With regard to the improved glass concrete 10% of the weight of the P2 cement we have 19.38MPa or 77.52% of 25MPa. For the improved glass concrete 15% of the weight of the P3 cement we obtain 20.03MPa or 80, 12% of 25MPa. The improved concrete 20% Glass of the weight of P4 cement meanwhile shows a value of 16.07MPa or 64.28% of 25MPA. We found that the compression results of the seventh day are between 60% to 80% of the value set for the formulation which is 25MPa. Which leads us to say that the compression results for the seventh day of 08/10/2022 are acceptable. We waited for the twenty-eighth of the concrete production which is 10/29/2022 for the realization of the last compressions. The control concrete P1 gives a value of 23.88MPa or 95.52% of 25MPa, the glass-enhanced concrete 10% of the weight of cement P2 presents a value of 24.66MPa or 99.04% of 25MPa, for the glass-enhanced concrete 15 % of the weight of the P3 cement we obtain 20.36MPa or 81.44% of 25MPa, The improved concrete 20% Glass of the weight of the P4 cement gives a value of 17.88MPa or 71.52% of 25MPa. We observe that the results of compression on the 28th day are significantly higher than those on the 7th day. In addition, P2 presents a result superior to that of the control concrete 24.66 MPa > 19.49 MPa. We

also note that the value of P2 is very close to the normal fixed during the formulation of the concrete. Therefore, we can say that the result of compression of the 28th day of the improved concrete of the glass 10% of the cement P2 is acceptable compared to the others (P1, P3, P4). Table 2 shows the compression results of the concretes produced on 01/10/2022.

.Table 2.Sag and compression tests

SAG AND COMPRESSION TESTS (NFP 18-451/18-406)								
SITE					UJKZ(LETRE)			
MOLD SIZES					16×32			
NATURE AND DOSAGE OF CONSTITUENTS					Crushed gravel 15/25 et 5/15			
					Natural sand			
					Concrete: CIMFASO CPA 45			
					Water: Robinet (ONEA)			
CONCRETE CONSISTENCY					Cone sag (cm) : 05;5,6;5;3.9			
					Vibration by: manual tapping			
N	Dates			Age	Mass	Breaking load		Compressive strength
	PART OF A STRUCTURE Simple design concrete							
	confection	reception	test	(days)	(g)	(KN)	(MPa)	
1	01st		08		15000	354.64	17.64	
2	10		10	7	15100	385.91	19.19	**19.49**
3			2022		15000	435.45	21.66	
4	2022		29		15100	481.77	23.96	
5			10	28	15000	442.72	22.02	**23.88**
6			2022		15000	516.18	25.67	
PART OF STRUCTURE Glass concrete 10%								
1	01		08		15000	456.80	22.72	
2			10	7	15100	343.78	17.10	**19.38**
3			2022		15100	368.43	18.34	
4	10		29		15000	506.61	25.19	**24.66**
5			10	28	15000	426.22	21.20	

6	2022		2022		15000	554.80	27.59	
PART OF STRUCTURE Glass concrete 15%								
1	01		08		15100	430.60	21.42	
2			10	7	15000	382.76	19.04	**20.03**
3			2022		15100	395.45	19.65	
4	10		29		15100	365.61	18.18	
5			10	28	15000	382.67	19.03	**20.36**
6	2022		2022		15000	480.34	23.89	
PART OF BUILDING Improved concrete 20% Glass								
1	01		08		15000	397.44	19.75	
2			10	7	15100	260.71	12.94	**16.07**
3			2022		15000	312.50	15.54	
4	10		29		15100	519.04	25.81	
5			10	28	15100	303.85	15.11	**17.88**
6	2022		2022		15000	255.92	12.73	

Other similar research has proved that the cement replacement rate of about 10-40% has very satisfactory results, stating that the properties of cement concrete based on glass powder mainly depend on several factors such as the particle size, level of replacement, color and type of glass, age and curing temperature. These same researchers were able to observe that fine glass aggregates can be used up to 100% of fine aggregates in mortar and concrete without negative effects on mechanical properties and durability when the particle size is less than 1 mm [1]. This allows us to appreciate our work but also by challenging us on the need to make an in-depth study on certain factors such as the size of the particles, the level of replacement, the color and the type of glass, the age and the hardening temperature if we want to improve the quality of our concrete. Since in our work we limited ourselves to the variations in the quantities of glass added replacing the cement without making an analysis of the properties of the glass. Other researchers also endorsed in 2014 that use in cementitious matrices as a cement substitute was the most suitable application due to its potential pozzolanic properties. They also showed in their research, the influence of the variation in the quantity of cement replaced by glass waste on several mechanical properties considered essential to ensure the performance of concretes in structural repair, such as compressive strength, the modulus of elasticity, linear shrinkage and tensile strength, was analyzed. The results of their study indicate the potential use of this waste for cement concretes they concluded that the replacement rate of 5% gave the best results [10]. These researchers justified part of our study which is the quantity of glass in replacement of cement. In 2018, researchers also focused on the efficient recycling of waste glass, one of the silica-based industrial by-products, and using it as a substitute for cement for sustainable construction. In their research they used waste glass powder in concrete as a partial replacement for cement, which was estimated at 20% of the cement (by weight) was replaced with glass powder and the resulting concretes were tested for their mechanical properties and durability. In addition, porosity and phase identification studies were also carried out by the same researchers. After an age of 90 days, the concrete exhibited the highest compressive strength [11]. The results of their research indicate that glass powder helps to improve the mechanical, microstructural and durability properties of concrete and as such its use in concrete will contribute to sustainability. Due to the efficient use of waste materials, the reduction of associated carbon dioxide emissions and lower production costs. In 2017 researchers showed that using glass powder in concrete reduces its discharges, as well as the cost and footprint of concrete. They concluded that the glass powder improves the mechanical properties at a later age thanks to its pozzolanic activity, the glass powder improves the pore structure and the durability of the concrete and in addition the glass powder considerably reduces the penetrability of the ions. concrete chloride [7].

5. CONCLUSION

Concrete is a material that is often seen as a potential place for waste, due to its composite nature and because it is widely used. Which means that if a waste can be used in concrete, then certainly large amounts of that waste can be recycled. This work focuses on the recovery of glass waste from solar modules. Glass was added to concrete in powder form as a replacement for cement. The glass-enhanced concrete 10% of the weight of the P2 cement presents a result superior to that of the control concrete 24.66 MPa > 19.49 MPa. We also note that the value of P2 is very close to the normal fixed during the formulation of the concrete. Therefore, we can say that the result of compression of the 28th day of the improved concrete of the glass 10% of the cement P2 is acceptable compared to the others (P1, P3, P4). An in-depth study on certain factors such as particle size, level of replacement, color and type of glass, age and curing temperature is necessary if we want to improve the quality of our concrete.

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