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Basalt Powder Waste Application as Affordable Concrete Admixture

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Abstract. Different weather conditions, like temperature and humidity influence on the performance of concrete structures to which they are normally subjected, especially at earlier stage of their service life. One of practical measures has been the regulation of the setting time of fresh concrete. Some admixtures are used in concrete to regulate the setting time and therefore increase structures performance under given situation. Almost all admixtures used in Rwanda are being imported from outside the country and this is one of factors affecting the construction cost. A big quantity of basalt powder at different sites in the country is left without being used and has been negatively impacting the environment. This study aimed at analyzing the potentials of basalt powder waste used in concrete as admixtures in different percentages, e.g. 0%, 5%, 10%, 15% and 20%. Different investigations on concrete incorporating basalt powder as admixture, such as the setting time, workability and compression tests were conducted. The results showed that the gradual incorporation of basalt powder waste as admixture up to 20%, accelerated the setting time more than 13 times, but decreased the compressive strength of concrete by around 24.5%, with comparison to normal concrete strength. The application of basalt waste in concrete would contribute not only to the reduction of environmental pollution but also to the provision of more affordable admixtures for mortar and concrete.

Key words: Admixture, Basalt powder waste, Compressive Strength, Concrete, Setting time, Workability.

1. Introduction

The widespread application of concrete in construction of different structures and under different conditions has increased the requirement not only in its quantity, but also its high quality. Concrete used should ensure the adequate performance of implemented structures under any condition to which they are exposed. Some special conditions, like high temperature, humidity, etc require that admixtures are added to the concrete mixture immediately before or during mixing in order to regulate its setting time or sustain some desired properties (Kosmatka and Wilson, 2011). In Rwanda, those admixtures have been in use especially when the concreting is performed during sunny period or under humid conditions. These admixtures are usually imported from abroad, and they are still expensive, especially with consideration of transportation services cost. In Rwanda basalt waste materials, produced by some construction industries, are disposed in the environment, and consequently they have been causing human health and sanitation concerns. Till today, this waste has been under use only as aggregates, especially in road construction projects, while its great part still remained improperly dumped in the environment. The utilization of basaltic waste would become a valuable contribution not only for preservation of the environment, but also in offering affordable product, while using local materials, and this is the main objective of the study. Among others, some specific objectives were identification of ordinarily used admixtures for concrete and their properties, survey on the availability of basalt waste in Rwanda, and determination of properties of fresh and hard concrete mixed with basaltic powder.

Basalt rock has been under use in construction projects all over the world, including Rwanda. Also some previous works on the use of basalt waste in cement or concrete are available. Feng (2013), using the experimental study on mechanical properties of basalt fiber reinforced concrete, he found that the mixture with basalt fiber would efficiently enhance the ductility of the concrete and improve the compressive strength and split tensile strength of concrete matrices in different ages. He concluded that the compressive strength of concrete in the age of 3days and the split tensile strength of concrete in the age of 28 days were improved more significantly, by 9% and 19% respectively. Dobiszewska and Beycioğlu (2017) used four types of common cement which were CEM I, CEM II/A-S, CEM II/A-V and CEM II/B-V for investigating the influence of waste basalt powder on selected properties of cement paste and mortar, where they established the positive effect on those properties and concluded that the incorporation of waste basalt powder into cement mortar as a partial substitution of cement was environmentally friendly and economically feasible. In their study about effect of basalt powder on the properties of cement composites, while modifying cement mortar by basalt powder in amount of 10, 20 and 30% by weight of cement, Uneik and Kmecova (2013) realized that basalt powder had a positive effect on the consistency of fresh cement composites and the strength of hardened composite. The initial and final setting time were prolonged with the increase of the basalt content. During their study on effect of basalt powder addition on properties of mortar, Dobiszewska et al. (2019) established that the addition of basalt powder as a replacement of cement leads to deterioration of compressive strength, while the flexural strength of mortar improved in some cases. The study on mortar properties with basalt powder subjected to high temperatures, showed that the ratio of basalt powder does not change the strength reduction rate, and that the flexural strength performance of mortar mainly depended on fibre type and temperature rather than on basalt powder substitution (Akyuncu, 2019). In Rwanda, a study about engineering characteristics of volcanic rock aggregates found that they had a very high compressive strength and better permeability (Mutabaruka et.al, 2016).

Dobiszewska and Barnes (2020) carried out an experimental investigation to evaluate the potential usage of waste basalt powder in concrete production, where the waste basalt powder, replaced 10%, 20%, and 30% sand, and the workability, compressive strength, water transport properties, and microstructural performances were evaluated. Among other results, the study showed that the compressive strength of concretes could increase up to 25%. Dobiszewska and Barnes (2020) investigated on the use of waste basalt powder in mortar when used as a partial replacement of fine aggregate and the experiments were performed on mixtures containing up to 20% replacement of sand by basalt powder to determine the impact on the compressive and flexural strength of mortar as well as on the flow characteristics, density, and porosity. The results indicated that use of basalt powder as a partial replacement of sand leads to improvement of the compressive strength and flexural strength. The mortar porosity in the capillary pore range was reduced. The study on Use of basalt powder in a cementitious mortar and concrete as a substitute of sand showed that powder basalt could be used as an effective substitute of fine aggregate in cementitious mortar and concrete and this improved some properties of cementitious mortar and concrete and enabled for the management of industrial waste (Dobiszewska, 2016). Among other results, the experimental study on basic mechanical properties of basalt fiber Reinforced concrete established that basalt fiber significantly improved the toughness and crack resistance performance of concrete and the improvement effect was the highest with the basalt fiber content of 0.3% and 0.4% (Zhou et al, 2020). This study is conducted with addition and not replacement of basalt powder in concrete, in order to assess its performance as an admixture.

2. Research Materials and Methods

2.1. Materials

2.1.1. Basaltic powder waste

The basaltic rocks are available in north-western part of Rwanda in the volcanic region (Mutabaruka et al., 2016). Many of local industries have been using these rocks in different construction activities like road pavement, building construction, where they are crushed and used as road base, asphalt pavement, concrete aggregate, etc. For this study, the samples of basalt waste powder were taken from the basalt rock crushing plant belonging to one of local construction company, NPD COTRACO Ltd located in Musanze district. The Fig.1 shows the used basaltic powder sample.

2.1.2. Cement

During this study TWIGA cement M32.5 grade was used throughout the whole investigation. The Fig. 2 presents the packaged and stored TWIGA cement.

Fig. 1. Basaltic powder

Fig. 2. TWIGA cement

2.1.3. Coarse and fine aggregates

The fine and coarse aggregates with the sizes of 4.75mm and 20mm, as well as specific gravity of 2.61 and 2.655 respectively were extracted from local river. Those materials are shown in Fig.3 and Fig.4 respectively.

Fig. 3. Fine aggregates

Fig. 4. Coarse aggregates

2.1.4. Water used

Clean water was used for mixing and curing of concrete.

2.2. Methods

During the mixing Process, the design mix proportion 1:2:3 for cement, sand and coarse aggregate respectively was considered, while the used W/C ratio was 45% of cement.

2.2.1. Experimental Design and Laboratory Test

The purpose of this laboratory experiment was the determination of the compressive strength using concrete specimen, prepared with incorporation of basaltic powder added as admixture. The compressive strength was determined at 28 days of curing on the cubes of 150mm size. Other important tests like sieve analysis, setting time and workability of concrete mixed with basaltic powder were also checked. Details on these tests are given below, while respective results are presented in section 3.

2.2.2. Sieve analysis of sand

This test is conducted to determine the distribution of fine aggregate samples using standard sieve meshes, and this is one of aspects used to assess the aggregates quality.

2.2.3. Used apparatus

Standard sieves of different holes' diameter in mm, shaking machine, laboratory balance, tray, Scoop, time stop watch, and calculator. The ordinary normal procedure was used in order to achieve the standard test results.

2.3.4. Standard consistency test

The consistency of cement is taken when a vicat plunger is allowed to penetrate, with the reading characterized by the standard consistency values in the range between 5-7 mm from the bottom or 33-35 mm from the top of mould. *Tools used for this test are*: vicat with plunger, needle, stop watch, glass plate, tray, balance and measuring cylinder (Fig.5).

Fig. 5. Used tools (from left to right: Vicat apparatus with plunger and needle, stop watch and balance)

2.3.5. The setting time test for cement

As many constructions projects are subjected to different extreme conditions such as humidity or high temperature, the setting time of concrete needs to be checked in order to ensure its quality at earlier stage. The setting time of cement paste is presented into two states that are initial and final setting. The initial setting is regarded as the time elapsed between the moments under which the water is added to cement and the time when the paste starts losing its plasticity, while the final setting is regarded as the time elapsed between the moment at which the water is added into cement to the moment when the paste has completely lost its plasticity.

Apparatus used*:* movable rod with cup, needle, standard vicat mould, needle with hallow circular cutting edges of 5mm diameter and weight balance. The standard procedure was used for this test as presented below (see also Fig.6). The initial setting time procedure is presented below:

1. Use approximately 300 gram of dry cement with additional of 0.85 p (p=weight of water for standard consistency to make paste).
2. Fill the mould with paste, then fix specific needle to moving rod apparatus.
3. Release the needle to penetrate cement paste.
4. Note the time and depth to which the needle penetrates the cement paste.
5. Repeat the procedure until the penetration will be 34.5-35.5 mm from the top of mould, means that it is 5±0.5mm from the bottom of mould.
6. Plot a curve between time (Minutes) and unpenetrated height in mm.
7. Find on graph initial setting time when penetration of needle is within 5±0.5mm.

Fig. 6. Initial setting time test

The procedure used for the final setting time test is the following:

1. Attach needle with circular cutting edge.
2. Release the needle slowly
3. The time when the needle makes impressions on the hardened cement paste is recorded.

Slump Test**:** The workability is described as ability of fresh concrete to be easily transported, compacted, and placed without any reduction of concrete qualities. The most commonly method used to measure the workability of fresh concrete in laboratory or on site is slump test.

Apparatus: Slump cone (with bottom diameter=200 mm, top diameter=100 mm, and height=300 mm), weighing balance, tray, standard tamping rod, concrete mixing machine.

Compression Test: The compressive strength is the one of the most important properties of hardened concrete which describes its ability to resist forces. This test is mainly conducted on 28 days hardened concrete by using compression testing machine and it plays an important role in controlling and conforming the quality of concrete.

Apparatus: cube moulds 150mm size, weighing machine, ramming rods, compression testing machine. The Fig. 7 shows the mould and used balance

 

Fig. 7. Used cube mould (left) and balance (right)

3. Results and discussion

As it was stated in section 2, the conducted experiments are: sieve analysis, consistency, setting time, workability and the compressive strength. Established results are presented and discussed in this section.

3.1. Sieve analysis

Following the procedure presented earlier, established results are presented in Table 1.

Table 1. Sieve analysis

Sieve size(mm)	Weight of aggregate retained(g)	% of aggregate retained	Cum % of aggregate retained	% of aggregate passing
4.75	8.33	1.40	1.40	98.60
2.36	21.62	3.65	5.05	94.45
1.18	195.38	32.94	37.99	62.01
0.6	123.81	20.88	58.87	41.13
0.3	145.14	24.47	83.34	16.66
0.075	97.56	16.45	99.79	0.21
pan	1.26	0.21	100.00	0.00
Total	**593.1**	**100.00**	**286.44**	**313.06**

Fineness Modulus=cum % of aggregate retained/100= 286.44/100=2.8644

From the above table the following can be underlined:

- The value of fineness modulus indicates that the used aggregates are "fine aggregates" because its value is within 2-3.2 standard range of fine aggregate as it is recommended by standards
- The maximum sieve size used is 4.75 mm, and minimum is 0 075 mm and the retained aggregates are 1.40% and 16.45% respectively. Referring to IS 383 (Bureau of Indian Standards, 2016), it can be concluded that this is a fine aggregate of zone II

3.2. Standard consistency test

The consistency test results for normal cement and cement mixed with basaltic powder are presented in Table 2 and Table 3, respectively.

Table 2. Normal consistency of cement

S/N	% of water	Initial reading	Final reading	Height of penetration
1	20	40	34	6
2	22	40	11	29
3	24	40	6	34

From Table 2, it can be seen that the established consistency of cement was 24% of water, and therefore the cement paste was normal (Mishra, 2014).

Table 3. Normal consistency of cement mixed with 5% basaltic powder

S/N	% of water	Initial reading	Final reading	Height of penetration
1	20	40	38	2
2	22	40	35	5
3	24	40	31	9
4	26	40	29	11
5	28	40	16	24
6	30	40	7	33

From Table 3, it is noted that the consistency of cement mixed with 5% of basaltic powder was 30% of water. The same test with 10%, 15% and 20% of basaltic powder showed the similar percentage of water.

3.3. The setting time test results

3.3.1. Initial setting time test

Following the recommended procedure the following quantities were used: Mass of cement =300gr; Quantity of water=300*30%*0.85=76.50 gr .Test results with 5% of mixed powder are presented in Table 4.

Table 4. Setting time data of cement with 5% of basaltic powder

S/N	Time(in Minutes)	Initial reading	Penetration Height	Remaining Height
0	0	40	40	0
1	6.30	40	40	0
2	13.00	40	39	1
3	19.30	40	39	1
4	26.00	40	39	1
5	32.30	40	38	2
6	39.00	40	38	2
7	45.30	40	37	3
8	52.00	40	36	3
9	58.30	40	36	4
10	65.00	40	36	4
11	71.30	40	36	4
12	78.00	40	36	4
13	84.30	40	36	4
14	91.00	40	36	4
15	97.30	40	34.5	5.5

3.3.2. Final setting time

The Fig. 8 demonstrates the variation of penetrated height in function time.

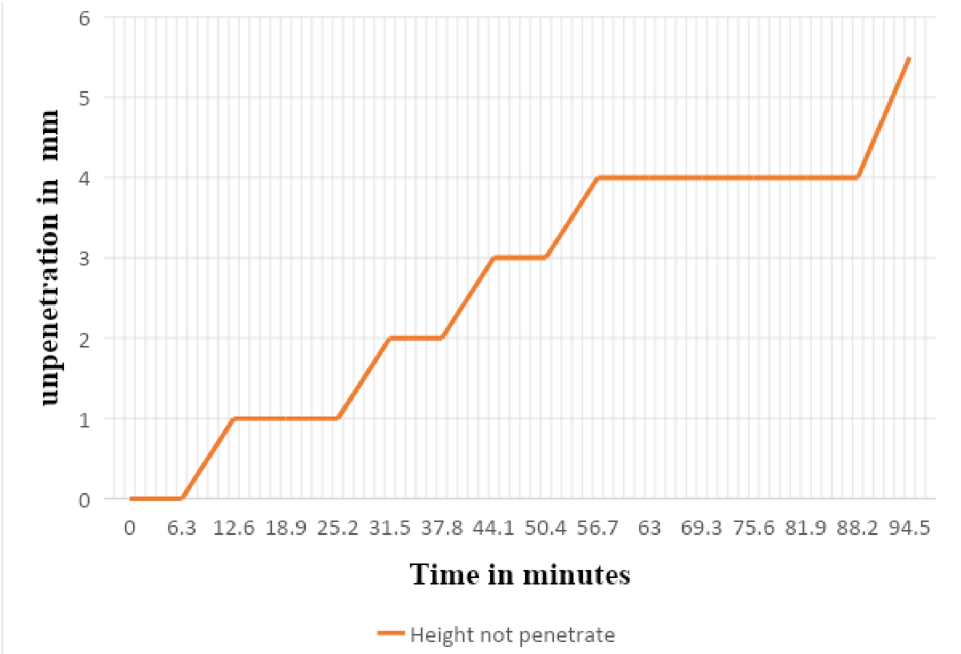

Fig. 8. Time versus unpenetrated height

Hence from chart above

- Initial setting is 97.30 minutes
- Final setting is 190 minutes

The setting time for concrete mixed with and without Basaltic powder is given in Table 5, while the respective chart is presented in Fig. 9.

Table 5. Initial and final setting time of concrete mixed with and without Basaltic powder

Basaltic in %	Water in %	Initial setting time in minutes	Final setting time in minutes
0	24	30	600
5	30	97.30	190.00
10	30	0-6.30	58.30
15	30	0-6.30	52.30
20	30	0-6.30	45.30

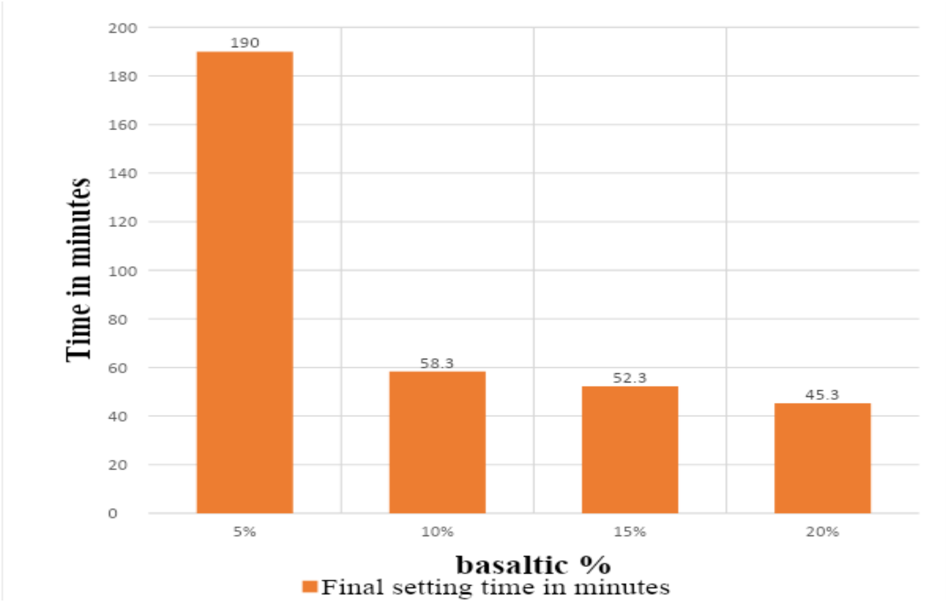

Fig. 9. Final setting time

The results in table 5 and respective Fig.8 show that the initial setting time at 5% basalt cement is 97.30 minutes and final setting time 190 minutes. Then with the increase of basalt content, the initial and final setting time gradually decreased, and it can be noted that the addition of basalt waste up to 20% decreased the sitting time from 600 to 45.30 minutes, giving a setting time reduction of more than 13 times. This may be due to the chemical composition of basalt with regards to the set accelerators admixtures (Kosmatka et al., 2008; Myrdal, 2007).The initial setting time lay between 0 and 6.30 minutes while final setting time are 48.30, 52.30 and 45.30 respectively. According to Krishna (2017), the standard initial and final setting time of cement is 30 and 600 minutes respectively. Therefore this result shows that basaltic powder should be the best mineral admixture to be used in humid condition due to its quick setting.

3.4. Slump Test

The used concrete mix is 1:1.6:2.7 (W/C=0.45) Ingredients are obtained by weight method.

The following standard procedure for this test was used:

1. Prepare apparatus.
2. Take mix proportion: 1:1.6:2.7 by weight; use Water cement ratio=0.45.
3. Sampling and measuring the concrete ingredients.
4. Prepare mixing machine and pouring the sample.
5. Cleaning internal surface of slump cone.
6. Fixing slump cone to the base on ground.
7. Fill the fresh concrete into slump cone in equal three layer and each layers should be compacted twenty-five blows.
8. Level the top of the cone by straight edge.
9. Remove the slump cone slowly upward and approach the empty slump cone near by the compacted concrete
10. Determine the slump result using gradual rule by measuring the difference between concrete and cone.
11. Obtain the height difference in mm as slump of concrete.

Slump test results are given in table 6, while respective chart is given in Fig. 10

Table 6. Observation of slump cone

S.N	Basaltic powder in percentage (%)	Height of slump H_1(mm)	Height of subsided concrete H_1(mm)	Slump (H_1-H_2 =mm)
1	0	300	234	66
2	5	300	236	64
3	10	300	246	54
4	15	300	237.5	62.5
5	20	300	231.5	68.5

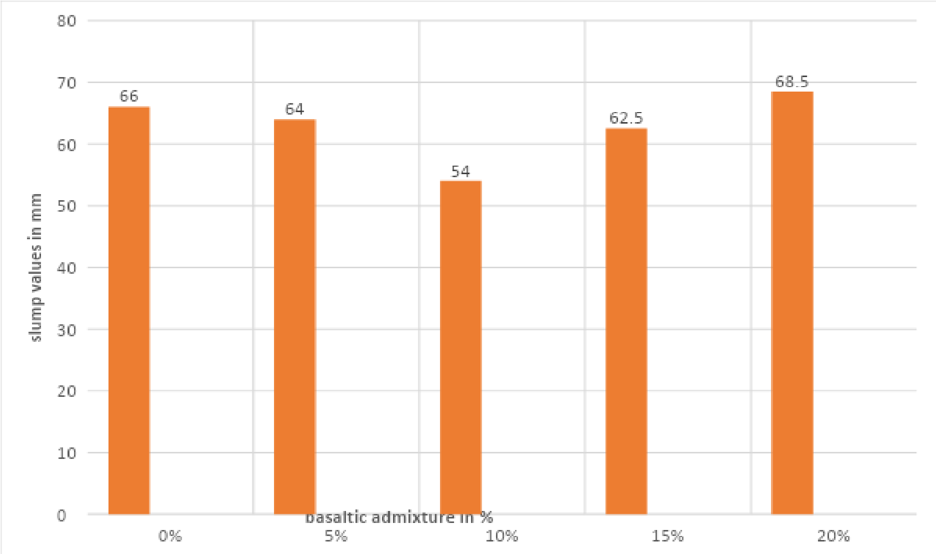

Fig. 10. Slump test results

From the results in Fig.10, it can be observed that initially the slump decreased with addition of 10% basalt powder waste from 66 mm up to 54 mm, and then it started increasing and became 68.5 mm at 20% basalt powder in concrete. Also, staying on this Fig.10, it is noted that the overall slump decrease was only around 3.7%. This situation may be explained by the fact that the structure of basalt allows a slight water absorption until it is saturated. In general, according to standards, the normal slump of concrete should be within 50-100mm for normal reinforced concrete, placed with vibration (Bureau of Indian Standards, 1959). Therefore the obtained slump results are normal and the incorporation of the tested basalt powder waste should not damage the workability of concrete.

3.5. Compressive strength test

The standard procedure was used and the compression test results are presented in Table 7, while the respective chart is presented in Fig.11

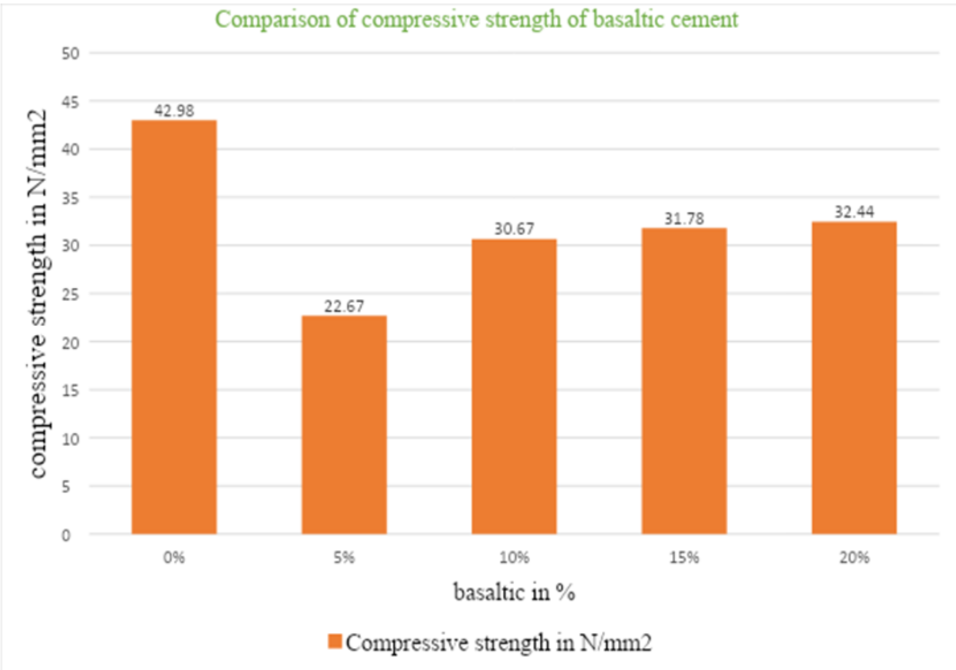

Fig. 11. Compression test results

Referring to the results presented in Fig. 11, it can be observed that the addition of 5% basalt powder waste in concrete, its compressive strength reduced abruptly by 52.80%. Then after that the gradual incorporation of basalt powder increased the compressive strength, to finally show a general decrease of around 24.5%. This situation may be attributed not only to the low final water/cement ratio, which made the hydration process difficult and not adequate, but also to the basalt chemical composition which prevented the strength from further sensitive decrease. However, the shown compressive strength at 20% basalt waste incorporation allows confirming that this concrete can still be used where appropriate, depending the designed compressive strength.

3.6. Discussion

The purpose of the study was to assess the potentials of basalt powder wastes as concrete admixture. Though all checked properties are important for assessing concrete performance, the influence on the fresh concrete setting time and on its compressive strength are here discussed. As it was presented earlier, many of previous studies related to basalt waste application in concrete checked its potentials as a replacement of one of concrete components (Dobiszewska Beycioğlu, 2020; Dobiszewska and Barnes,2020; Akyuncu, 2019; Dobiszewska and Beycioğlu, 2017; Uneik and Kmecova, 2013) and quite all reported about the positive influence of basalt material on concrete properties. Only Dobiszewska et al., (2019) established that the addition of basalt powder as a replacement of cement leads to the deterioration of compressive strength. There was a little about the use of basalt powder as concrete admixture, and therefore only concrete standards values regarding the setting time, slump and compressive strength, as well as basalt chemical composition were used for comparison.

Setting time test results showed that the addition of basalt waste decreased both the initial and final sitting time for fresh concrete (Fig. 9), but remained under the standards limits (Krishna, 2017). This is considered as positive result to consider basalt powder waste as set accelerator admixture.

The results showed a general decrease of compressive strength of concrete with incorporation of basalt powder waste, comparing with normal concrete, even if there was a gradual increase after 5% basalt powder waste addition (Fig.11). These results are in acceptance with previous findings (Dobiszewska et al., 2019). For application of this concrete, the % of basalt powder waste incorporation should depend on the designed concrete strength.

Finally, regarding the new admixture affordability, this is based on the local availability of basalt rock as its raw material, and it has also been confirmed by previous studies (Dobiszewska and Beycioğlu; 2017).

4. Conclusion

The general objective of this study was to investigate on the use of basalt powder waste in concrete as admixture, in order to take advantage from its local availability and solve the problem related to its negative impact to the environment. It has shown that the basalt rock is available in Rwanda, especially in Northern – Western province and currently has been used mainly in road pavement and building construction. During this study, the properties of concrete mixed with 0%, 5%, 10%, 15%, 20% basaltic powder like workability, setting time and compression strength were checked. The following key findings were established:

- Compared to plain concrete, the workability test was achieved up to 80% due to the variation of water quantity.
- The amount of water needed during mix was slightly greater than that of plain concrete, and therefore basaltic powder can be used as water reducer.

- The setting time of concrete mixed with basalt waste as admixture decreased with increase of percentages of basalt powder waste, and therefore the waste acted in concrete properly as admixture and would be suitable especially in humid condition.
- With increase of the basalt powder in concrete, the compressive strength decreased in the beginning, but after 5% and until fixed 20% basalt powder, the strength started increasing. However, this increase did not attain the compressive strength for normal concrete.

From the above, it can be concluded that the use of basalt powder waste in concrete would provide a local and affordable as well as a sustainable solution regarding set accelerator admixture. Concerning the concrete compressive strength, due to the initial reduction and then increase of the strength, a due care should be made to ensure the incorporated % of basalt powder does not decrease the designed concrete strength. Further study may check the durability of basaltic concrete with varying basalt powder at different ages. This study was more interested in setting time with consideration of other minimum requirements for concrete performances, and it did not establish the % of added basalt waste at which the standard compressive strength would be achieved; therefore this can be the scope for further study.

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