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Research Article

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Characterization of Compressed Earth Blocks Stabilized with Clay Pozzolana

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Abstract

The high cost of cement and its greenhouse effect on the environment have led to the use of alternative building materials in the production of block and bricks. This study seeks to investigate the properties of compressed earth blocks (CEBs) stabilized with clay pozzolana. CEBs of size 290 × 140 × 100 mm were prepared with 0, 10, 20 and 30% weight of clay pozzolana. The CEBs were compressed at a constant pressure of 5 MPa and cured. The blocks, after 7, 14, 21 and 28 days of curing were tested for density, water absorption, compressive strength, tensile strength and erosion resistance. It was found that the pozzolana content slightly improved the blocks' density. There was increase water absorption resistance of the stabilized blocks between 32.8% and 252% over the unstabilised blocks. The 30% pozzolana content block specimens gained 116.8% compressive strength and 62.1% tensile strength over the unstabilised blocks. Furthermore, there was a statistically significant difference in the erosion resistance between the stabilized blocks and the unstabilised blocks. The study concludes that the inclusion of the clay pozzolana generally improved the properties of the CEBs, and therefore recommended it for use in the building of low-rise houses.

Keywords: Clay pozzolana; Compressed Earth Blocks (CEBs); Compressive strength; Erosion test; Splitting tensile strength

Introduction

Construction industry plays a major role in most economies and its activities are also vital to the achievement of the socio-economic development goals of providing shelter, infrastructure and employment [1]. However, the cost of renting or buying a house in developing countries is relatively high to the ordinary citizens due to the high cost of building materials among other factors. Therefore, most people in low-income communities in developing countries wish to become house owners and get at least a suitable accommodation has become an illusion. The most popular and common walling unit used in most developing countries is sandcrete block, and its essential constituent is cement. The problem with the cement production is mainly the importation of clinker and gypsum which requires a huge foreign exchange. This is coupled with high inflation and interest rate, which affect the price built up of cement in most developing countries [2].

The use of earth blocks as walling units is common in most rural parts of Ghana. In recent past, the collapse of buildings as a result poor nature of earth blocks used has been dramatic in developing countries [3]. Some buildings in some cities of Ghana, especially, Accra and Kumasi have seen the collapse of one form or the other [4] which could be attributed to many factors including the materials used. Researchers have now focused on the type of materials used, and how to introduce additives such as fibres and chemicals to strengthen the building units [2,5]. To this effect, the Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR) of Ghana has developed clay pozzolana. Studies on the use of the clay pozzolana have concentrated on concrete and mortar mixes [6-10]. Therefore, there is limited information on the use of clay pozzolana in soil matrix such as compressed earth blocks to enhance its properties for use as walling units. Lack of knowledge on the use earth blocks stabilised with clay pozzolana coupled with the correct quantity of clay pozzolana in the blocks has necessitated for this study.

This study, therefore, investigates the properties of compressed earth blocks stabilised with clay pozzolana. The aim of this study is to improve the quality of compressed earth blocks to be used to construct decent but affordable houses. The objectives of the study are: to determine the physical properties of compressed earth blocks enhanced with clay pozzolana; to determine the mechanical properties of compressed earth blocks enhanced with clay pozzolana; and to determine the durability (erosion) properties of compressed earth block stabilised with clay pozzolana.

The use of pozzolana either as a partial replacement of ordinary Portland cement or with lime has gained widespread popularity in construction. Pozzolan can be defined as a siliceous or alumino-siliceous material with very fine particles, and in the presence of water, it reacts with calcium hydroxide released by the hydration of Portland cement at ordinary temperatures, to form compounds of possessing cementing properties [11]. Pozzolana in the context of concrete technology is actually acidic oxides that will react with the excess basic calcium hydroxide formed during hydration of cement and form 'neutral' hydrates [12]. Pozzolana is sometimes preferably used for the construction of structures because of their resistance to the alkali-aggregation reaction, improved durability properties which are due to resistance to sulphate attack [13]. Relatively low-cost materials with cementitious properties are natural pozzolana such as volcanic tuff, clay and waste products from industrial plants such as slag, fly ash and silica fume [14]. Till recently, the use of pozzolana all over the world was as an additive or admixture to cement binders, mainly in mass concrete work, like dam constructions [15]. To reduce the consumption and dependency on cement, utilization of pozzolanic materials as supplementary cementing materials has become the leading research interest in the area of cement and materials research in recent decades [16]. Recently, as a supplement of cement, the utilization of pozzolanic materials in cement and concrete manufacturing has increased significantly [16]. Pozzolana is therefore important replacement of cement in recent time due to its sustainable properties.

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Materials and Methods

Materials

The materials used for this study are earth/soil, clay pozzolana, and water from Ghana, where the investigation was conducted. The sample of soil used for the study is shown in Figure 1 and was obtained from Sunyani, Brong Ahafo region in Ghana. The soil sample was selected because it is the soil used for preparing earth blocks for building houses in Sunyani. The properties of the soil sample used are presented in Table 1. The particle size distribution of the soil sample is shown in Figure 2. The clay pozzolana (Figure 3) used was obtained from (BRRI), pozzolana factory at Fumesua in Kumasi. Tap water, which is supplied by the Ghana Water Company was used. The water used was fresh, good for drinking, colourless, odourless, tasteless and free from contaminants and impurities.

Methods

Preparation of blocks: Compressed earth blocks of size 290 × 140 × 100 mm were prepared with soil, clay pozzolana and water. The clay pozzolana contents used in the mix were 10%, 20% and 30% by weight of the soil. The quantity of water used was as per the optimum moisture content (23%) by weight of the soil. Manual hand mixing method was used. The required quantity of soil was measured with electronic weighing balance and spread on a mixing platform, after which the required quantity of clay pozzolana was also measured and spread on the soil. The soil and pozzolana were mixed until a uniform mixture was obtained, then the required water was measured and sprinkled on the soil-pozzolana mixture while mixing continued until a uniform paste was obtained. This process was followed for each mixing batch according to the pozzolana content (10%, 20% and 30%.). It must be noted that there was another mixing batch without pozzolana (0%) content, thus for producing unstabilised block specimens. The mixture was then placed in the BREPAC pressure gauge block making the machine and manually pressed at a constant pressure of 50 bar (5 MPa) following previous study [17] and then pushed up to produce the compressed earth block as shown in Figure 4. The blocks were placed under a shed as shown in Figure 5 and cured by covering them with a polythene sheet. Thirty (30) replicates of the blocks were produced for each mix making a total of hundred and twenty (120) block, out of which five (5) blocks from each mixing batch were tested at 7, 14, 21 and 28 days, respectively. Each block sample produced was carefully labelled for easy identification.

Testing of blocks: The physical properties of the block specimens were determined using density and water absorption test. At the 7, 14, 21 and 28 days curing period, the density of the block specimen was determined in accordance with BS EN 772:11 [18]. The block specimens

Figure 1: Soil sample.

Property	Results
Proctor test	
Optimum moisture content (%)	23
Maximum dry density (Mg/m³)	1.9
Atterberg limits	
Liquid limit LL (%)	49.2
Plastic limit PL (%)	26.9
Plasticity index PI	22.3
Particle size distribution	
Gravel (>2 mm) (%)	40
Sand (2 - 0.063 mm) (%)	22
Silt (0.063 - 0.002 mm) (%)	6
Clay (<0.002 mm) (%)	32

Table 1: Properties of the soil sample.

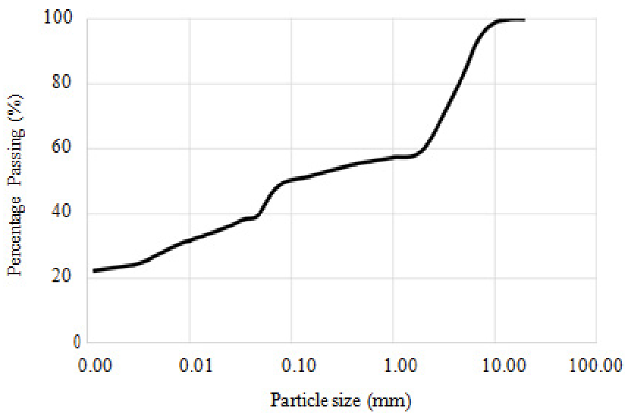

Figure 2: Particle size distribution of soil.

Figure 3: Bag of pozzolana.

Figure 4: Pressure gauge machine for block making.

Figure 5: Moulded blocks ready for curing.

were dried until consistent mass was obtained using electronic weighing balance. The dimensions of each block specimen were measured with a tape measure and the overall volume calculated. The block specimens were then weighed and the density calculated. The water absorption test was to determine the rate of moisture absorption capacity of the block specimens at 28 days of curing. Water absorption by capillary testing was performed in accordance with BS EN 772-11 [18]. Block specimens were oven dried at a temperature of 35°C until a consistent mass was obtained after 28-day curing. The mass of each block specimen was weighed and recorded. The bedside (290 × 140 mm) of each block specimen was immersed in a constant head-water bath to a depth of 5 mm for 10 min, and the mass of each water-absorbed block specimen was measured and the water absorption of by capillarity calculated.

The mechanical properties of the block specimens were determined using compressive strength and splitting tensile strength tests. The block specimens' average dimensions were measured and weighed at the 7, 14, 21 and 28 days curing period. The tests were conducted using Controls 50-C46G2 with a maximum load of 2000 kN. Compressive strength test was conducted in accordance with BS EN 772-1 [19]. The load was applied on each block specimen until failure of the block and compressive strength calculated. Splitting tensile strength test was conducted in accordance with BS EN 1338 [20]. Each block was placed in the testing machine with splitting jig components placed centrally on top and below the block (Figure 6) and load applied at a rate of 0.05 N/mm²/s until the block failed. The maximum load at which each block failed was recorded and the splitting tensile strength calculated.

The erosion property of the compressed earth blocks was determined using erosion test. The erosion test was conducted using the water spray method to measure the depth of erosion and determine the resistance of the blocks to continuous rainfall. The water spray test was conducted in accordance NZS 4298 [21]. A pressure washer was used with pressure release valve to control water flow and reduce pressure. Each block specimen was placed with their external face exposed to a circular area of 100 mm diameter of shield screen. The block specimen was sprayed by a pressurized jet of water, at 50 kPa which was 470mm away from the spraying nozzle (Figure 7) for sixty (60) minutes. The spraying was interrupted at every fifteen (15) minutes to allow for measurement of the eroded pit created in the block specimen. The probability rate of each block specimen was then calculated.

Data and statistical analysis: The data obtained were inputted into Microsoft Office Professional Plus Excel, version 2016 for generating graphs for analysis. The graphs were charted using trend lines, bars, legends and axis labels. Correlation tests were conducted to determine the relationships that exist between properties of the compressed earth block specimens tested. Holm-Sidak method of All Pairwise Multiple Comparison Procedure was adopted with overall significance level at 0.05. One-Way Repeated Measures Analysis of Variance (One-Way RM ANOVA) test and One-Sample t-tests were conducted with the help of SigmaPlot, version 12 to determine the significant difference between the control and the pozzolana stabilised compressed earth blocks.

Results and Discussion

Physical properties

Density and water absorption tests were used to determine the physical properties of the compressed earth blocks. Five block specimens were tested in each test category and the mean value used for analysis. The density obtained in each test category was expressed to the nearest kg/m³. Figure 8 shows a graphical representation of the results of the dry density of the compressed earth blocks.

Figure 6: Set-up of tensile strength test.

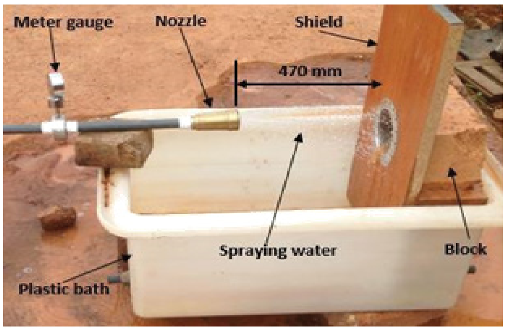

Figure 7: Set-up of watering spray test.

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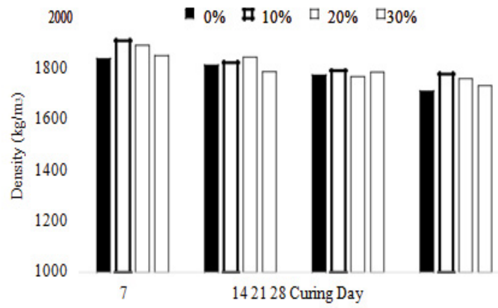

Figure 8: Dry density of the CEBs.

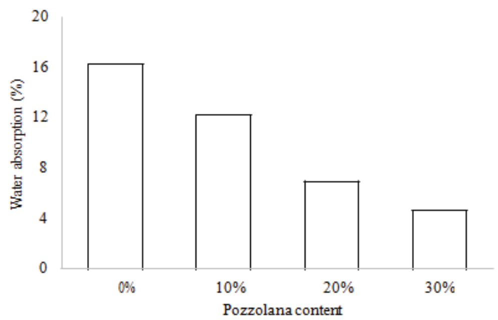

Figure 9: Water absorption rate of the CEBs.

It could be seen that the dry densities mean values of the unstabilised block specimens and the pozzolana stabilised block specimens were quite close for all the curing days. However, there was the increased density of all the stabilised block specimens over the unstabilised block specimens of the curing days 7 and 28. The difference between the stabilised block specimen and the unstabilised block specimens is between 2.5% to 2.9%. This indicates that the density of the block specimen did not undergo obvious change with the inclusion of the clay pozzolana. A previous study [5] conducted with chemical (Pidiproof LW+) stabiliser recorded similar results where the density of specimen seems to be almost the same. This was due to an equal mass of the mix used for producing each test block specimen and constant compaction rate used, as was confirmed by an earlier study [22].

The rate at which the compressed earth block specimens absorbed water recorded a gradual decline as the amount of pozzolana content in the block specimens increased (Figure 9). Among the pozzolana stabilized earth blocks, the 10% content recorded the highest water absorption of 12.2% while specimen with 30% pozzolana content recorded the lowest rate of 4.6%. The decline in water absorption from the control block specimen to the pozzolana stabilised block specimen ranged between 32.8% and 252.2%. This means that the inclusion of the clay pozzolan improved the resistance of the compressed earth block against absorption of water. The improved water absorption of the compressed earth blocks could be attributed to the binder (pozzolana) ability to fill the voids between particles of the soil, thereby reducing the porosity of the blocks [22]. A similar trend has been attributed to the fineness of clay pozzolana to bridge the voids in the soil particles in the blocks [4-5,23]. To determine if the difference in water absorption of the control block specimen and the stabilized block specimen are significant or not, One-Sample t-test was conducted. The two-tailed p-value obtained was 0.0312, which means there is the statistically significant difference between the control and the stabilised blocks. This means the impact of the clay pozzolana on the compressed earth blocks is significant in terms of water absorption resistance.

Mechanical properties

The mechanical properties of the compressed earth blocks were determined using compressive strength and splitting tensile strength tests. The compressive strength test results are shown in Figure 10. The result shows a consistent increasing trend of strength development of the block specimens with increased curing days. This means the compressive strength of all the compressed earth blocks increased with increased curing age. The strength development against curing age is consistent with Bediako and Atiemo [7] findings which attributed the increased strength to soil-pozzolana reaction through hydration. It can also be observed that all the pozzolana stabilised block specimens performed better in compressive strength than the unstabilised block specimens. Furthermore, it can be seen that the higher the pozzolana content in the block specimens the better the compressive strength. The mean compressive strengths of the compressed earth blocks on the 28-day curing were 1.73 MPa, 2.75 MPa, 3.38 MPa and 3.75 MPa for 0%, 10%, 20% to 30% pozzolana content, respectively. These were close and above most of the recommended minimum values for use in structural work according to TS 704 [24] and Houben and Guillaud [25] recommendations of 1 MPa and 2 MPa, respectively. The 30% pozzolana content block specimens gained 116.8% compressive strength over the unstabilised block specimens. The increase in strength can be attributed to the pozzolana reaction with water which forms strong and rigid hydrates, fill spaces and bind particles together independent of reactions with the soil [23,26].

To determine whether the difference in compressive strengths between the unstabilised block specimens and the pozzolana stabilised block specimens on 28-day curing age, One-Way RM ANOVA test was conducted. The test result provided a p-value of 0.001, which means there is a statistically significant difference between the unstabilised block specimens and the pozzolana stabilised block specimens. This implies that the inclusion of the clay pozzolana in the compressed earth blocks significantly improved the mechanical property of the blocks. This is consistent with previous studies [27] with cement and chemical which also recorded significant improvement in strength. In order to determine the exact pair where the difference occurred, All Pairwise Multiple Comparison Procedure (Holm-Sidak method) was conducted. The result obtained is presented in Table 2. It can be seen clearly that significant difference existed between each pair of the unstabilised block specimens and the pozzolana stabilised block specimens with p-values less than 0.05.

Figure 11 presents the splitting tensile strength result of the compressed earth block specimens stabilised with clay pozzolana at the 28-day curing age. It can be observed that, the tensile strength increase

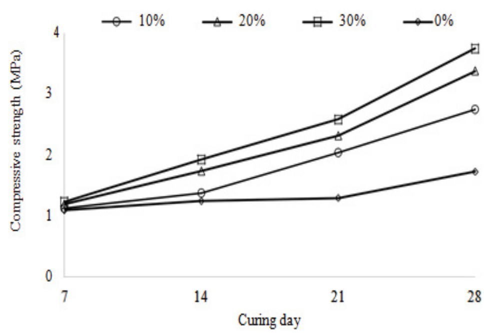

Figure 10: Compressive strength of the CEBs.

Comparison	Diff. in means	t	p-value	Sig.
30% vs. 0%	2.002	21.067	<0.001*	Yes
20% vs. 0%	1.636	17.215	<0.001*	Yes
10% vs. 0%	1.002	10.544	<0.001*	Yes
30% vs. 10%	1	10.523	<0.001*	Yes
20% vs. 10%	0.634	6.671	<0.001*	Yes
30% vs. 20%	0.366	3.851	0.002*	Yes

Table 2: All pairwise multiple comparison for compressive strength.

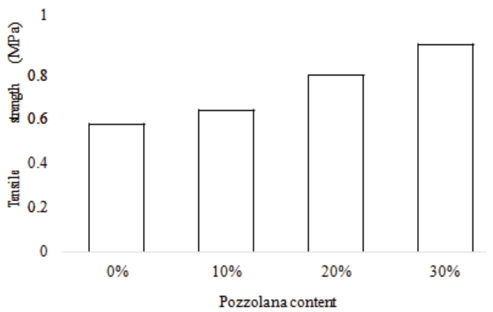

Figure 11: Tensile strength of the CEBs.

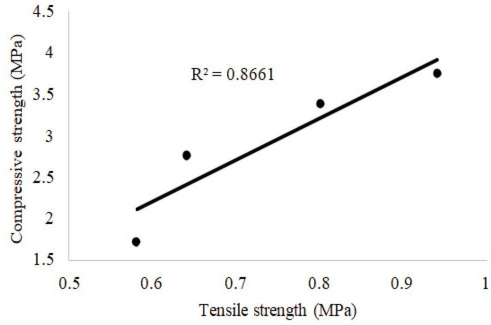

Figure 12: Linear relationship between compressive strength and tensile strength.

with the increased pozzolana content. All the pozzolana stabilised block specimens recorded improved strength over the unstabilised block specimens. There were 20.3%, 37.9% and 62.1% increase in tensile strength for 10%, 20% and 30% pozzolana stabilised block specimens, respectively over the unstabilised block specimens. This suggests that the pozzolana content in the soil matrix helped to improve the blocks resistance against splitting. Similar results were obtained in previous studies [26-28] with cement.

One-Way RM ANOVA test result provided a p-value of 0.025, implying that there is a statistically significant difference between the unstabilised block specimens and the pozzolana stabilised block specimens. This means that the inclusion of the clay pozzolana contributed to the improvement in the tensile strength of the compressed earth blocks. All Pairwise Multiple Comparison Procedure (Holm-Sidak method) was conducted to identify the pairs where the difference occurred. The result obtained shows that the difference in the tensile strength was between the 30% pozzolana stabilised block specimens and the unstabilised block specimens with a p-value of 0.036 as shown in Table 3. All the other pairs recorded p-values greater than 0.05, which means there was no significant difference between them.

The relationship between compressive strength and tensile strength of the compressed earth blocks stabilised with clay pozzolana at 28 day of curing is summarized in Fig. 12. The result indicates a strong positive linear relationship between compressive strength and tensile strength of the compressed earth blocks stabilised with clay pozzolana with coefficients of determination (R2) of 0.866. This means the compressive strength of the compressed earth blocks increased with corresponding increase in tensile strength. Furthermore, the relation of compressive strength to tensile strength is given by a factor of 3.87. Figure 12 This result is consistent with the findings in previous studies [29-31].

Erosion property

The erosion property of the compressed earth blocks was determined using water spray method after 28-day curing age. It could be observed from Figure 13 that the higher the pozzolana content the lower the rate of erosion. This means that the inclusion of the clay pozzolana in the compressed earth blocks helped to improve the blocks' resistance to erosion. From the test results, it could also be seen that the pitting depth obtained ranged between 1.5 and 2.0 mm per minute. A similar trend was obtained by Thomson [29] where he obtained 0 to 2 mm of pitting depth in a stabilised soil block. The pitting depth of the unstabilised block specimens was deeper than the stabilised block specimens. This is because the pozzolana as a binder held the particles of soil together to minimize the rate of erosion of the block specimens. The test result also gives clear indication that the compressed earth blocks stabilised with clay pozzolan was slightly erosive, which is consistent with the study by Danso [30] with natural fibres in the soil matrix. Therefore, it will be prudent to protect the wall surface from direct rainfall with plaster when the units are used for walling. One-Sample t-test produced a p-value of 0.001 between the 30% pozzolana stabilised block specimens and the unstabilised block specimens,

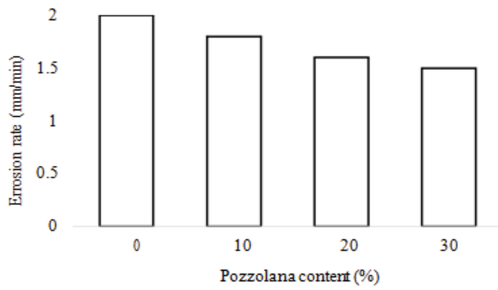

Figure 13: Erosion resistance of the CEBs.

Comparison	Diff. in means	t	p-value	Sig.
30% vs. 0%	0.36	3.314	0.036*	Yes
30% vs. 10%	0.3	2.762	0.083	No
20% vs. 0%	0.22	2.025	0.238	No
20% vs. 10%	0.16	1.473	0.421	No
30% vs. 20%	0.14	1.289	0.394	No
10% vs. 0%	0.06	0.552	0.591	No

Table 3: All pairwise multiple comparison for tensile strength.

which means there is the statistically significant difference between the unstabilised and the stabilised blocks at 0.05 significant level. The other pairs recorded no significant difference between them.

Summary and Conclusion

The study was carried out to investigate the properties of compressed earth blocks stabilised with clay pozzolana. Based on the results obtained, the study provides the following summary of findings:

1. The study recorded a slight increase in density of the stabilised block specimens over the unstabilised block specimens, and also showed an increased resistance of water absorption leve of the stabilised block specimens over the unstabilised block specimens. This, therefore, indicates an improvement in the physical properties of the pozzolana stabilised compressed earth blocks.
2. The 30% pozzolana content block specimens gained 116.8% compressive strength and 62.1% tensile strength over the unstabilised block specimens. This provided a statistically significant difference in mechanical properties of the stabilised block specimens over the unstabilised block specimens.
3. It was also evident that the erosion property of the stabilised compressed blocks improved, as the inclusion of the clay pozzolana in the compressed earth blocks helped to improve the blocks' resistance against erosion. Though there was an improvement in the rate of erosion, the stabilised compressed blocks recorded some degree of erosion.

From the foregoing, it can be concluded that the engineering properties of the compressed earth blocks were generally improved with the inclusion of the clay pozzolana. The highest improvements was recorded at the 30% clay pozzolana contents for almost all the tests conducted, and therefore recommend 30% weight of clay pozzolana content for use in earthen structures. It is also recommended for further studies to use waterproof admixture to further improve the water resistance property of the blocks.

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