RP Current Trends In Engineering And Technology (e-ISSN: 2583-5491)
Vol. 5, No. 1 (January – March 2026) pp. 7–13

RESEARCH PLATEAU PUBLISHERS

Cite this article: Lekshmi M.S., Thangamani Bindu, Earth-based mortar reinforced with coir fibre using bio-extract as admixture - An alternative to conventional mortar, *RP Cur. Tr. Eng. Tech.* **5** (2026) 7–13.

Original Research Article

Earth-based mortar reinforced with coir fibre using bio-extract as admixture - An alternative to conventional mortar

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ARTICLE HISTORY
Received: 10 April 2026
Revised: 26 May 2026
Accepted: 27 May 2026
Published: 12 June 2026

KEYWORDS
Earth-based mortar; Coir fibre; Cashew nut shell liquid; Compressive strength; Shrinkage; Sorptivity.

ABSTRACT
The 12th millennium goal of sustainability aims at responsible consumption and production. Consumption of natural resources to a greater extent as raw materials for building construction, often result in their depletion. Intensive researches are going on to introduce green materials that can substitute the conventional materials such as river sand, natural aggregates, calcareous and siliceous materials, gypsum without causing a negative impact on environment. Stabilized earth with bio-extracts and plant fibres can be a sustainable alternative. In this study, feasibility of using raw mud stabilized with coir fibre and bio admixtures as an alternative binder for cement mortar has been investigated with respect to the strength, shrinkage and sorptivity characteristics. It was observed from the experimental study that the stabilized mud with 0.5% coir fibre dispersed in 10% cashew nut shell liquid (CNSL) reduced sorptivity and linear shrinkage respectively by 67% and 79% of raw mud mortar while maintaining minimum compressive strength.

1. Introduction

The world agricultural footprint is fast growing resulting in large quantities of agricultural wastes that are ill-managed. If managed well it could be recycled by retrieving fibres from disposed leaves and fruit bunches for making fibre reinforced mortar, bricks and concrete [1]. In India, about 600 million tonnes of biomass waste have been generated by agricultural sector alone [2]. Construction industry became the major consumer of natural resources and major contributor of greenhouse gases [3]. One way of attaining sustainable development for developing countries is to build with locally available materials reinforced with natural fibres extracted from agricultural waste residue [4].

Another environmentally friendly building material is natural earth. When mixed with water and natural fibres it decorated most of the ancient mansions and monuments in the form of mud blocks, mud walls, mortar and plaster. Yet it lost its footprints over decades with the progress of technology. The technological advance has side tracked earth-based building materials from the path of cement-based building materials to that extent till the world started facing issues such as global warming. Numerous researches went in parallel to reduce the carbon emissions from cement by replacing it with agricultural residues such as sugarcane bagasse ash, rice husk ash etc. [2, 5, 6]. Such studies have resulted in reducing the CO_2 emission from construction materials to extent of 0.68 tonnes/tonn of cement produced [7].

Instead of exploiting natural resources, indigenous technologies need to be developed which utilize minimum resources at maximum efficiency. The decline in earth constructions might be attributed to the susceptibility of earth to moisture ingress and vulnerability to shrinkage cracks. In order to increase the acceptance level of earth as a binder for mortar and plaster, in the mind of common people, detailed experimental study need to be conducted on earth-based mortar samples. This paper investigates the feasibility of utilizing earth-based mortar as an alternative to conventional mortar on the basis of mechanical properties such as compressive strength and durability characteristics such as sorptivity and linear shrinkage when reinforced with coir fibre. The water repellent properties of cashew nut shell liquid (CL) as dispersing agent in mitigating moisture ingress of raw earth-based mortar is also examined.

2. Earth-based mortars and plasters

Earth has been the raw material for construction from time immemorial. As raw mud is easily vulnerable to erosion, shrinkage and termite attack it needs to be stabilized with suitable additives (Oral Communication with Padmasree G. Shankar on April 12, 2014; Prof. Eugene Pandala on April 16, 2014; Er. P.K. Sreenivasan on May 6, 2014 and Er. Aravind P.I. on May 11, 2014). The additives added to enhance the strength and durability properties of mud can be categorised as (i) Mineral additives (Sand, Pozzolana and ashes) (ii) Synthetic additives (Portland cement, Hydraulic lime, Hydrated lime, Gypsum, Soap and Bitumen) (iii) Vegetable additives (Fibres, Vegetable oils and fats, Tannins, Gum Arabic, Saps and Latexes, Copal and Molasses (iv) Animal additives (Fibers, Blood, Casein, Animal Glue, Oils and fats, Urine and Excrements [8].

2.1 Fibre-reinforced mortar and plaster

Fibers, both natural and artificial, can mitigate crack propagation to a greater extent. It can be used for reinforcing mud blocks or mud walls and for reinforcing mud mortar to prevent cracking [9]. Fibres have the ability to bridge between grains of the cement matrix. When they are uniformly distributed into the mortar, plastic shrinkage may be minimized and micro cracks are prevented from developing into macro cracks [10]. Shorter and flexible fibres are found to perform better in earth masonry [11]. Fibres can be natural such as those extracted from plants, animals and agricultural wastes or steel, carbon, glass fibres or synthetic made from polyester, polypropylene and polyethylene [12, 13].

Ashour et al. [14] made a study on the shrinkage of natural plastering materials for straw bale buildings affected by reinforcement fibres and drying. They observed that the reinforcement fiber had greater effect on the drying shrinkage than sand. The use of natural fibers, such as straw, have been used in adobe and other traditional forms of earthen construction for many thousands of years, to reduce shrinkage cracking and improve tensile and compressive strength [15].

The results from the study conducted by Paulina and Jose (2016) showed that the addition of oat straw or typha fiber-wool can contribute to decrease in linear drying shrinkage of an earth-based plaster, even when a clayish earth with low expansibility is used. [16] in their study on the influence of natural fibre dosage and length of adobe mixes damage-mechanical behaviour came to the conclusion that addition of pig hair to earthen materials decreased the drying shrinkage cracking. They found that a dosage of 0.5% by weight and 7mm length fibre as optimal to improve crack control, flexural toughness and impact strength without statistically affecting strengths. Sreekumar, M.G., and Nair, Deepa (2012) found in their study that the addition of 0.5% of coir industry waste resulted in about 20% increase of the compressive strength of stabilized lateritic blocks. Coconut coir fibre coming under fruit fibre category has been used for as reinforcement for this study.

2.2 Bio extracts as admixtures

Ancient Chinese used sticky rice soup as admixture for enhancing strength and durability [17]. Linseed oil and cactus extract were found effective in reducing capillary water absorption of lime mortar [18, 19]. Cashew nut shell liquid extracted from the kernel of cashew nut has been proven to be an eco-friendly antioxidant and a dispersing agent [20]. The cashew nut shell contains 25-30% dark reddish brown viscous phenolic liquid known as Cashew Nut Shell Liquid and abbreviated as CL [21]. It is reported that the side chain of cashew nut shell liquid imparts a hydrophobic nature making it water repellent and resistant to weathering [22, 23]. CL is thus well known for its water repellent properties and hence has been used to check sorptivity of mud mortar under study.

This experimental study focuses on the effectiveness in the utilization of locally available materials such as coir fibres from coir industry and cashew nut shell liquid (extract of roasted cashew nuts) in enhancing the strength and durability of raw mud mortar, which could be used as an alternative to cement mortar.

3. Experimental program

The experimental investigation was undertaken to examine the effect of coir fibres as reinforcement and cashew nut shell liquid as bio-extract in enhancing the strength and durability of mud mortar. Compressive strength at the end of 28th day was chosen as the strength parameter and sorptivity and linear shrinkage on 28th day are chosen as the durability parameters for the study. The compressive strength, sorptivity and linear shrinkage of raw earth and fibre reinforced earth mortar with and without bio-extract are determined through laboratory experiments conforming to respective standard codes.

3.1 Materials

The materials chosen for the experimental study are raw earth as base material for mortar, coir fibres from coir industry as fibre reinforcement and cashew nut shell liquid as bio-extract.

Sample earth: Earth sample for the study was collected within a depth range of 2-5m, from Ernakulam district, Kochi, Kerala, dried and sieved through IS sieve size 2mm and stocked in bins. The physical properties of both soil samples are tabulated below in Table 1.

Table 1: Physical properties of sample earth.

Properties	**Specific Gravity**	**pH**	**Organic matter (%)**	**Grain size distribution (%)**			**Total silt and clay fractions (%)**
				Sand	**Silt**	**Clay**	
Sample earth	2.67	5.48	0.69	47.2	34.8	18	52.8
Standard values	> 2.2	4.5- 5.5 Moderately acidic	<=1 %	30-40	40-45	18-22	60
IS Code	*IS:2720 (Part 3) -1980*	*IS:2720 (Part 26) -1987*	*IS :2720 (Part 22) -1972*	*IS:13077-1991*			

Fibre: Coir fibres (F) were collected from a coir industry at Alappuzha, Kerala. The properties of the fibre are recorded in the Table 2. The coir fibres were treated in 5% NaOH solution for 72 hours to remove cellulose and lignin, was washed, dried and cut into desired length of 20 mm (Fig. 1).

Cashew nut shell liquid (CL): CL was obtained by dry roasting of cashew nuts from a local cashew nut factory at Kollam, Kerala. The main constituents of CL are phenolic compounds with long side chain substitution at the meta position. Commercially available technical cashew nut shell liquid (Anacardium occidentale L.) contains mainly cardanol (decarboxylated anacardic acid) and cardol [23, 24]. The colour of liquid was dark brown (Fig. 2). It was found to have specific gravity of 0.98 and viscosity 57.3 centipoise.

Table 2: Physical and biological properties waste coir fiber.

Physical		**Biological**	
Diameter	0.32 mm	Lignin	39.62%
Density	1.35 g/cc	Cellulose	22.99%
Tenacity	14.85	Ash	2.99%
Breaking elongation	26.53%	Pectin	2.40%
Swelling in water	88.35%		

Figure1: Coir fibre

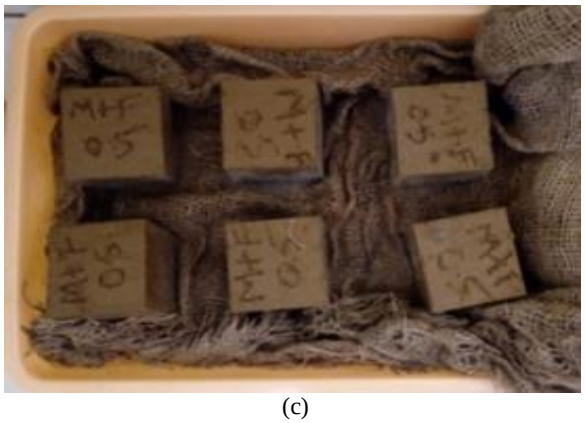
Figure 2: Cashew nut shell liquid

3.2 Specimen preparation and designation of mortar mixes

Sample earth passing through 2 mm IS sieve was mixed dry. Coir fibre, 20mm in length was added in 0.25% and 0.5% of the weight of the soil samples. The fibres were randomly oriented. Water adequate to maintain the consistency of mortar conforming to a flowability of 100% was added to the dry mix. During the mixing, the fibres were added by hand in stages to get a homogeneous matrix (Fig. 3a). Mixing was continued to get a uniform distribution of fibres throughout the matrix, without aggregation of the fibres which will result in congestion and conglomeration of the matrix. To the fibre reinforced earth mortar, cashew nut shell liquid was added as bio-extract in a constant proportion of 10% by weight of the sample which was arrived by trial and error. Standard cube moulds (70.6×70.6×70.6 mm) were cast for compressive strength and sorptivity tests (Fig. 3b) and bar moulds for measuring linear shrinkage (250×25×25mm). which were cured by gunny bag curing (Fig. 3.c) for 28 days.

(a)

(b)



(c)

Figure 3: (a) Mixing of ingredients of raw earth mortar, (b) Casting of mortar cubes, (c) Gunny bag curing.

The earth mortar samples were designated with M for raw mix prepared from the two-sample earth, MF_x for fibre reinforced earth mortar and MF_xCL_{10} for fibre reinforced earth mortar dispersed in 10% CLF- denotes coir fibre and subscript *x* denotes the fibre %, CL –cashew nut shell liquid.

3.3 Evaluation of strength and durability parameters

The tests conducted for this study are 28-day compressive strength test for evaluating mechanical property of mud mortar and water sorptivity and linear shrinkage tests for evaluating durability parameter.

3.3.1 Compressive strength test

The compressive strength of the cubes was tested according to IS: 2250 -1981 in a compression testing machine. Earth mortar cubes were prepared with the required amount of water, and admixtures, demoulded after 7days and kept under gunny bag curing with occasional sprinkling of water till the time of testing. Three mortar cubes for each mix were tested on 28 day from the time of casting, average value taken and noted as 28-day compressive strength value.

3.3.2 Sorptivity test

In order to determine the resistance of mud mortar cubes against water penetration water sorptivity tests was conducted. Sorptivity test was done as per ASTM C 1585. Cube specimens were covered on lateral sides with adhesive tapes in order to provide uni-directional capillary suction and the cubes were immersed in tray with water in contact with 5mm depth of the cube from the base. The increase in mass of mortar cubes were measured after 5, 10, 15, 20, 25 and 30 minutes of immersion (Fig. 4) after wiping excess water from the cube base. The increase in mass per unit area over the density of water is plotted versus the square root of the elapsed time. The slope of the line using linear regression analysis is accounted for the sorptivity. The formula used for calculating sorptivity is given below:

$$I = S\, t^{1/2}, \quad (1)$$

where I is the combined water retention per unit area of inflow surface (mm); S is the sorptivity (mm/s$^{1/2}$); t is the time elapsed (s). I is also expressed as the change in the mass of the specimen (Δmass) per unit area over the density of water.

3.3.3 Linear shrinkage test

Raw mud is susceptible to drying shrinkage. The presence of fibres inhibits crack formation and propagation. Hence this test is done to check the effect of fibres in controlling crack formation and propagation. The linear shrinkage of earth mortars, without or with fibres, determined by shrinkage bar moulds, must not exceed 3%, respectively as per NZS 4298 (1998). In this study shrinkage bar mould with dimensions 250×25×25 mm were used (Fig. 5). The inside surface of the linear shrinkage mould was greased to prevent the soil from sticking to the walls. Initial length of the mould is measured as L_1. A sample of soil was prepared using the required water content for each mix. This soil mix was then pressed into all the corners of the dish and neatly smoothened off with the spatula so that the soil exactly fills the mould. The filled mould was then left in the shade for 28 days. The soil sample dries and shrinks in length. Final length of the soil sample is taken as L_2.

$$\% \text{ Linear shrinkage} = \frac{L2-L1}{L2} \times 100 \quad (2)$$

Figure 4: Sorptivity set up.

Figure 5: Linear Shrinkage moulds.

4. Results and discussion

In order to examine the feasibility of using earth mortar duly reinforced with coir fibre dispersed in cashew nut shell liquid as a suitable alternative to cement mortar, strength and durability parameters were evaluated. The effect of coir fibre as reinforcement and cashew nut shell liquid as bio extract in enhancing the above parameters is discussed in this section. The consolidated test results are presented in Table 3.

4.1 Compressive strength

Raw earth mortar had sufficient compressive strength of the MM3 grade (3-5 N/mm^2) as per IS: 2250-1981 before the addition of coir fibres. Because of the low density of fibres the compressive strength got decreased to MM2 grade. The effect of 0.25% and 0.5% waste coir mat fibres in the compressive strengths of the selected soil samples are discussion below:

It had a compressive strength of 3.22N/mm^2 in its raw state. The addition of 0.25% and 0.5% waste coir mat fibre resulted in a decrease of compressive strength by 4.5% (3.08 N/mm^2) and 8.7% (2.94 N/mm^2) respectively. With the addition of 10% CL, compressive strength further decreased by 25% (2.42 N/mm^2) and 27.6% (2.33 N/mm^2) for 0.25% and 0.5% of coir fibres respectively.

Fibres are incorporated to reduce the shrinkage cracks on drying. Since they are having low specific gravity, addition of fibres normally decreases the compressive strength. Futher decrease in compressive strength due to the addition of 10% CL may be attributed to the slippery nature of CL which reduces bondage between soil particles and fibres. Yet it was greater than 2 N/mm^2 for masonry mortar to be used without

protection as per IS: 2250- 1981. The results for 28 day compressive strength of earth-based mortar are presented in a bar chart (Fig. 6).

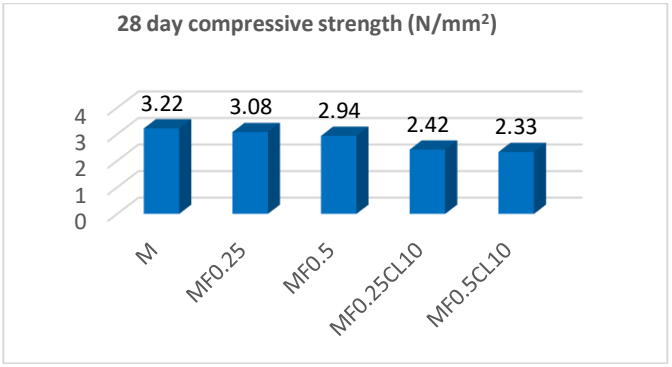


Figure 6: Compressive strength of earth-based mortar.

4.2 Sorptivity

Raw earth is vulnerable to moisture ingress and will dissociate fully when immersed under water. The presence of fibres increases water absorption as fibres form channels for transportation of water. The progressive increase in sorptivity was mainly due to the formation of interconnecting channels by these fibres paving path for easy moisture propagation [25]. In this study the effect of a natural bio extract, cashew nut shell liquid in checking water penetration was examined.

The earth sample in its raw state had poor sorptivity (1.45 mm/min$^{0.5}$) as per ASTM C 1585. When it was reinforced with 0.25% and 0.5% coir fibres sorptivity further increased respectively to1.53 mm/min$^{0.5}$ and 1.62 mm/min$^{0.5}$. With further addition of 10% CL, sorptivity got drastically reduced to 0.48 mm/ min$^{0.5}$and 0.57 mm/ min$^{0.5}$ respectively.

Generally, the presence of fibres results in increased water absorption in earth-based mortar. Accordingly, the sorptivity of earth mortar increased with the increased percentage of coir fibres. The addition of 10% CNSL had profound effect in reducing the sorptivity of coir fibre-reinforced earth- mortar. The role of CL as a moisture repellent is thus proved. This may be due to the presence of long hydrophobic chain structure of CL. The results are presented in the bar charts below (Fig. 7).

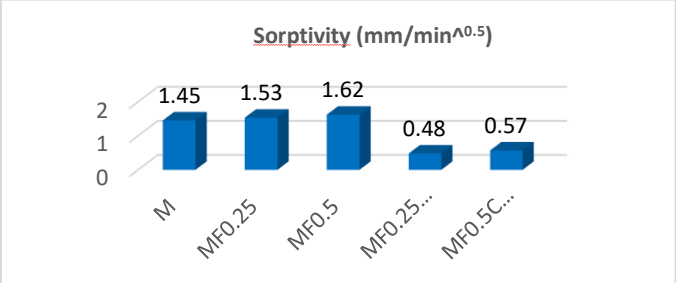


Figure 7: Sorptivity of earth-based mortar.

4.3 Linear Shrinkage

New Zealand standard 4298 (1998) suggests 3% as the limit for linear shrinkage of earth mortars. The effect of coir fibres in inhibiting shrinkage is discussed with respect to the earth-based mortar in this section.

Earth based mortar in raw state showed linear shrinkage of 6.98% which got lowered to 6.34% and 5.22 % with the addition of 0.25% and 0.5% coir fibre respectively. The lowest linear shrinkage was obtained for earth mortar reinforced with 0.5% coir mat fibre dispersed in 10% CL (1.47%). It had been clear from the study that with increase in fibre content, linear shrinkage got reduced. The effect of CL was equally pronounced in reducing linear shrinkage for earth-based mortar. The results are presented in the bar charts (Fig. 8).

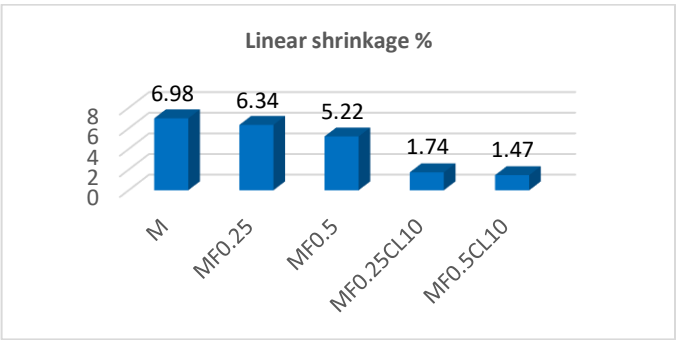


Figure 8: Linear shrinkage of soil samples.

The effect of coir fibre reinforcement and cashew nut shell liquid stabilization on mechanical and durability characteristics of earth-based mortar is presented in Table 3.

Table 3: Consolidated test results for earth-based mortars.

Sample designation	28 day compressive strength (N/mm^2)	Sorptivity (mm/min$^{0.5}$)	Linear Shrinkage (%)	Remarks
M	3.22	1.40	6.98	Sorptivity (poor grade) and shrinkage exceeding limits
$MF_{0.25}$	3.08	1.58	6.34	Shrinkage out of limit
$MF_{0.5}$	2.94	1.62	5.22	Shrinkage out of limit
$MF_{0.25}CL_{10}$	2.42	0.48	1.74	Recommended
$MF_{0.5}CL_{10}$	2.33	0.57	1.47	Least value for shrinkage and recommended
Standard values	MM2 grade >2	<0.77 (Excellent) 0.77- 1.29 (Good) 1.29-1.94 (Poor) >1.94 (To be rejected)	< 3	
Standard code	IS 2250-1981	ASTM C 1585	New Zealand standard 4298 (1998)	

It is clear from Table 3 that the addition of 10% cashew nut shell liquid resisted moisture ingress (61%-67% reduction) in 0.25% and 0.5% coir fibre reinforced-earth mortar. This is mainly due to the hydrophobic nature of its long chain phenolic structure, but was found to decrease the compressive strength, but *within the standard limits.*

It was equally effective in reducing the linear shrinkage of raw earth mortar by 79% which can be considered as an added advantage. As fibre content increases, sorptivity increases but linear shrinkage decreases. The dispersion of fibres in CL forms a hydrophobic coating around it which prevents further water uptake with the same amount of fibres. When the water uptake is arrested, loss of water through evaporation is also arrested which reduces the formation of air gaps in the mud mortar while drying which is the main reason for linear shrinkage. This justifies the decrease in linear shrinkage in fibre–reinforced mud mortars.

5. Conclusion

In order to ensure responsible consumption of resources so as to conserve the same for our future generations, recycling and reusing of natural resources should be practised at all stages of construction. The experimental study is an initiative to utilize agricultural residues such as coir fibres available in Kerala as reinforcement for natural earth mortar. The effect of a natural bio admixture, cashew nut shell liquid extracted from the kernel of cashew nuts available in plenty in Kerala, when used along with the coir fibres in enhancing the strength and durability of natural earth mortar had been investigated. The conclusions drawn from the study on earth – based mortars specific to the characteristics of the materials used and the range of parameters investigated are summarized below:

1. The raw earth sample had adequate compressive strength to be used as masonry mortar, but sorptivity and shrinkage values need to be further reduced for them to be recommended as an alternative to the conventional cement mortar.
2. The increase in sorptivity due to the addition of coir fibre (0.25% & 0.5%) was reduced by 67% by stabilizing with10% cashewnut shell liquid.
3. The addition of CL was found to resist moisture ingress mainly due to the hydrophobic nature of its long chain phenolic structure, but was found to decrease the compressive strength, but within the standard limits.
4. It was observed from the experimental study that linear shrinkage decreases with increase in the percentage of coir fibre. CL was found effective in controlling linear shrinkage of earth-based mud mortar by about 79%.
5. Considering a perfect balance between strength and durability parameters the earth mortar reinforced with 0.5% coir fibre dispersed in 10% CL has been recommended as a suitable earth-based mortar to be used as an alternative for cement.

Anyhow the experimental investigation had proved the effectiveness of agricultural waste like coir fibre and a natural extract like cashew nut shell liquid in enhancing the durability of earth-based mortar. The study is prone to create awareness among common man to indulge in the utilization of locally available materials thus minimizing exploitation of natural resources and attaining the motto of 12th goal of sustainability *"Doing better with less by wasting less".*

Authors' contributions

All authors contributed equally to the conception, design, experimental work, data analysis, interpretation of results, and preparation of the manuscript. All authors reviewed and approved the final version of the manuscript for publication.

Conflicts of interest

The author declares no conflict of interest.

Funding

This research received no external funding.

Data availability

No new data were created.

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