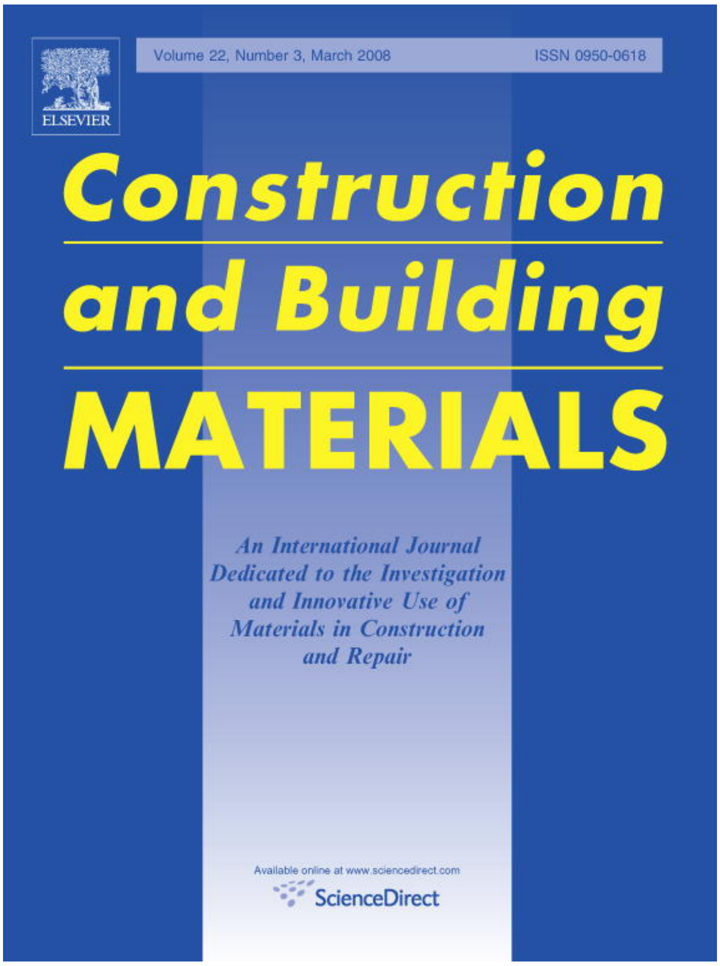
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The effects of the fiber contents on the mechanic properties of the adobes

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Abstract

In this study, compression and tensile tests were conducted for five different adobe mixtures. The important part of this study consisted of uniaxial compressive tests done with natural fiber mixtures. Thus, the results obtained from mechanical tests were presented in the form of stress–strain graphs. In addition, mechanical properties were related to the water content for workability, unit weight and fiber contents and discussions were given. The results show that as fiber content increases, compressive and tensile strengths decrease, and shrinkage rates decrease.

Keywords: Adobe; Straw; Mechanical properties; Fiber content; Clay content

1. Introduction

The adobe that can be described directly as earth is a sedimentation product and consists of sand, silt and clay mixture. Adobe is abundantly available in the world, and would not need a large amount of energy for its production and application, because they do not need heat treatment [1]. Thus, the material is very environmentally friendly and does not produce any CO_2 during its production, application, and lifetime process. Besides, the thermal, acoustic and fire resistant properties of these materials are very high [2]. They are used especially as walls in buildings. With these properties, today, the adobe is gaining importance again in developed countries [3–5].

On the other hand, adobe is sensitive against shrinkage because its water content needed for workability is very high. In its conventional applications, it is common to use natural fiber ingredients to address this problem [6–8]. In addition, since fibrous adobes have less the thermal conductivity, they provide heat (energy, fuel) savings in buildings [1].

The adobe does not get mechanical strength as high as concrete or burnt brick. However, Isik et al. [3] observed that the adobe is strong enough, ductile and resistant against earthquake. To improve the durability of adobes, their strength should be increased and their water absorption should be decreased. The most effective method to modify the adobe is the compaction of the earth and stabilization of them with additives. To reduce the water content effectively, plasticizers used in the concrete industry could be used, such as lignins or naphthalene sulfonates, which are readily available and cheap. Fiber, cement, bitumen, lime or cow-dung can be used to stabilize the adobe [5]. Besides, resin [9] or pozzolan [10] can also be used. The natural fibers like straw, coconut, sisal [8] can be used for additive; artificial fibers can also be used in adobes like plastic or polystyrene fabrics [6]. Bitumen emulsion can be used to prevent water absorption of fibers [8].

In this study, compressive strengths were tested by using different mixtures that have different contents of straw fibers and the adobes from five different sources. Thus, the effects of using different amount of fiber (straw) on especially compressive stress and strength were compared.

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The comparisons were also made with the nonfibrous samples and the results were evaluated in the light of the physical properties of the materials. In the experiments that were made with both fibrous and nonfibrous adobe samples, water content, specific gravity and shrinkage rate were discussed by connecting stress behavior and strength. Besides, tensile experiments are also added to these discussions. Thus, a conclusion was tried to draw about workability and practicability of these materials.

2. Properties of the materials

The adobe samples were taken from middle-north Europe (Germany). They had been stratified in different granule fineness and mineral contents with the effects of glacier movement. Grain size distributions of the materials (A1–A5) were determined according to the Sedimentation Method (Aerometer, Boyoucos-Casagrande, DIN 18123) and the mass fractions of clay, silt, sand are given in Table 1. Besides, specific gravity (ρ_s) and proctor gravity (ρ_{pr}) were given with water content (W_{pr}). Here, the results of the proctor experiment are important owing to showing the compatibility of adobe samples. Although the specific gravity of the samples are close to each other (2.67–2.69 g/cm^3, Table 1), proctor compacting factors show differences. These differences are especially coming from different proportions of the grain fraction. In this case, the clay content must be in certain limits for high degree of compaction (ρ_{pr}). This claim is valid for both compaction degree and the risen strength level related this degree. It can be correlated from Table 1, the highest proctor gravity is obtained by using about 15% clay, 25% silt, and 60% sand.

When it comes to the fiber material, this straw is obtained from wheat (triticium) stalk, which crop plant (poaceae). There are many different natural fibers that were mixed into adobes (earths) but cut or cracked straws are commonly used. In this study, the straws were cut in 5 cm length and added to the adobe mixture with some leafs after being weighed. The straws, which are about 3 mm in diameter and have a hollow structure, show a more flexible behavior than split fibers. Fiber samples, which had a circular cross section, were used for all the experiments. Thanks to this fiber structure, adobes dry faster. Fiber contents are given in tables (Table 2–7). It is known that, in practice, in the tamped adobes, straw fiber addition is suggested to be about 5–10 kg/m^3, however, as clay content increases; this proportion can be increased [11]. In this

Table 2
Physical properties of A1 fibrous adobe

Series	W (by wt.%)	ρ (g/cm^3)	Fiber rate (by wt.%)	Shrinkage rate (by vol.%)
1	22.2	1.67	0.89	14.5
2	27.3	1.64	1.38	10.9
3	31.1	1.56	2.42	7.56
4	40.5	1.53	3.84	5.65

Table 3
Physical properties of A2 fibrous adobe

Series	W (by wt.%)	ρ (g/cm^3)	Fiber rate (by wt.%)	Shrinkage rate (by vol.%)
1	18.8	1.83	0.78	16.2
2	23.9	1.76	1.36	13.1
3	28.9	1.62	2.41	9.21
4	34.2	1.56	3.23	7.32

Table 4
Physical properties of A3 fibrous adobe

Series	W (by wt.%)	ρ (g/cm^3)	Fiber rate (by wt.%)	Shrinkage rate (by vol.%)
1	27.2	1.82	0.72	24.1
2	32.3	1.79	1.03	20.3
3	35.8	1.64	1.59	15.7
4	41.0	1.58	2.27	11.0

Table 5
Physical properties of A4 fibrous adobe

Series	W (by wt.%)	ρ (g/cm^3)	Fiber rate (by wt.%)	Shrinkage rate (by vol.%)
1	22.2	1.77	0.85	9.40
2	25.2	1.58	1.31	6.85
3	26.5	1.56	2.51	4.18
4	28.1	1.49	3.34	3.67

Table 6
Physical properties of A5 fibrous adobe

Series	W (by wt.%)	ρ (g/cm^3)	Fiber rate (by wt.%)	Shrinkage rate (by vol.%)
1	32.0	1.72	1.03	20.3
2	44.5	1.67	2.20	17.8
3	48.1	1.54	2.82	16.5
4	51.5	1.43	3.24	12.8

Table 1
Physical properties of materials

Adobe	ρ_s (g/cm^3)	ρ_{pr} (g/cm^3)	W_{pr} (by wt.%)	Clay (by wt.%)	Silt (by wt.%)	Sand (by wt.%)
A1	2.67	2.14	8.70	14	20	66
A2	2.68	2.12	9.20	19	28	53
A3	2.68	2.09	8.90	26	23	51
A4	2.67	2.02	8.50	12	16	72
A5	2.69	2.09	12.0	33	20	47

Table 7
Physical properties of nonfibrous A1, A2, A3, A4, A5 for compressive test

Series	W (by wt.%)	ρ (g/cm^3)	Shrinkage rate (by vol.%)
A1	19.25	1.93	9.10
A2	20.00	2.08	13.40
A3	21.25	1.97	10.00
A4	24.40	1.82	11.25
A5	57.00	1.93	41.30

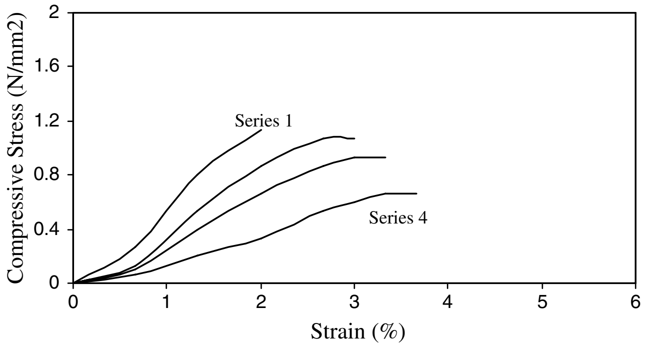

Fig. 1. Compressive stress–strain relation for A1 fibrous adobe.

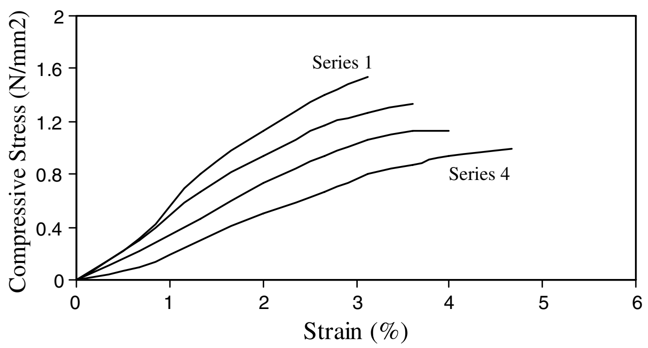

Fig. 2. Compressive stress–strain relation for A2 fibrous adobe.

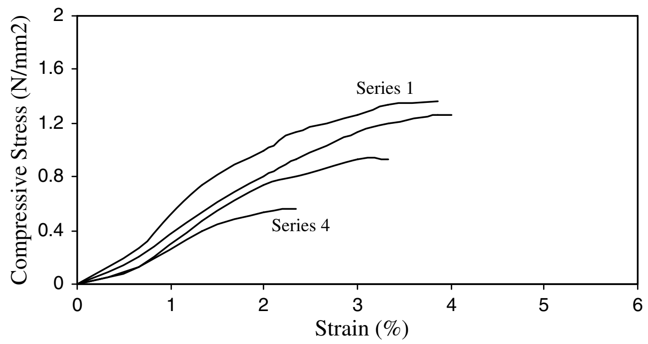

Fig. 3. Compressive stress–strain relation for A3 fibrous adobe.

study, it was seen that this rate should not exceed 0.5% limit (by weight) for normal adobe mixtures similar as in the literature. Otherwise, high deformation and creep risk of fibrous adobes increases and they show the properties of lightweight adobes.

Straws are soft fibers like polymer fibers. Thus, the E-modulus of them is low. Besides, the adherence of them to the matrix is weak. Therefore, at beginning of loading, they slip off and they do not have important positive effect on compressive strength. Similarly, because of their high elastic deformation (Figs. 1–5), they increase the creep risk

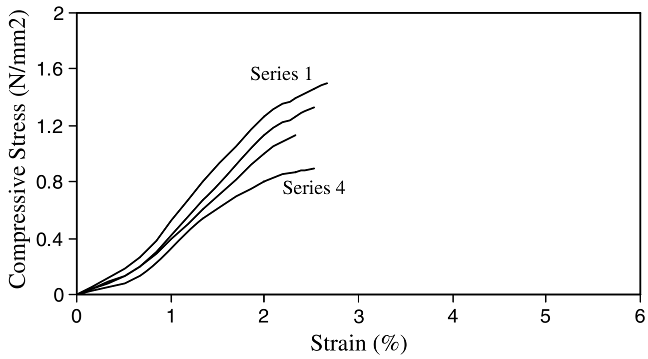

Fig. 4. Compressive stress–strain relation for A4 fibrous adobe.

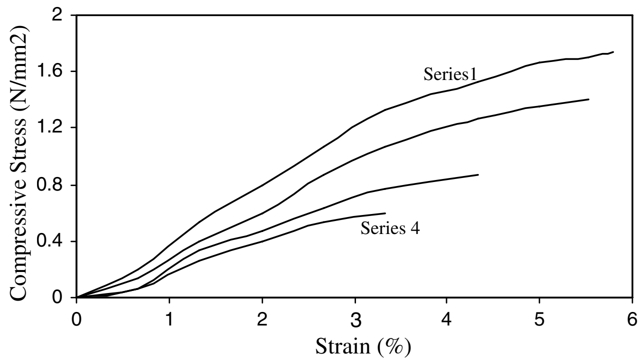

Fig. 5. Compressive stress–strain relation for A5 fibrous adobe.

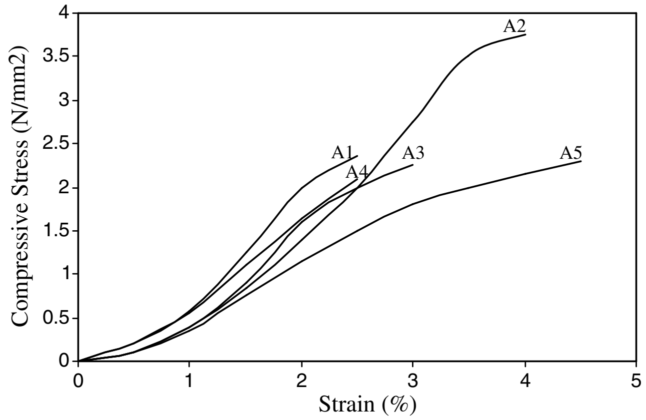

Fig. 6. Compressive stress–strain relation under compressive loads for nonfibrous A1, A2, A3, A4, A5.

of adobes. The main objectives of adding straw fiber to adobes are to increase green strength of adobes and to decrease the shrinkage rate (Tables 2–6).

3. Experimental method

The uniaxial compressive strength experiments were the main focus of this study. $10 \times 10 \times 10\ \text{cm}^3$ in dimensions, cubic in shape samples were produced and tested according to DIN 1045, DIN 1048, DIN 18952 [12] and these were left to dry in normal laboratory conditions (19–21 °C).

When compressive tests samples were being produced, the fiber contents were determined in four stages for each adobe admixture. These adobes were kneaded in an adequately wide and deep basin to ensure homogeneity. Later, they were left to dry until tamping consistency, and turned upside down in certain periods to evaporate water from every part at the same rate. However, when fiber content was increased, water content also increased a little (Tables 2–6) and tamping procedure was finished by rodding and shaking slightly. Then, the adobe mixtures that had been cast in moulds were removed from the moulds after 1–3 days and then, were left to dry until their weights remained constant. Drying period was varied from 14 days up to 28 days depending on their water contents under the laboratory conditions. During the experiments, it was seen that the cubic samples that were assumed as dried had hygroscopic water content of 1–2% by weight.

Six cubic specimens were prepared for each test series. A total of 150 compressive strength tests were conducted with nonfibrous samples and the results are presented in Figs. 1–6. The physical properties of these samples are given in Tables 2–7 respectively.

For tensile tests, prismatic specimens $160 \times 40 \times 20\ \text{mm}^3$ in dimension were prepared as fibrous and nonfibrous. A total of 60 tensile tests were conducted and the test results are presented in Figs. 7 and 8. Physical properties are presented in Table 8. The experimental test setup can be seen in Figs. 9 and 10.

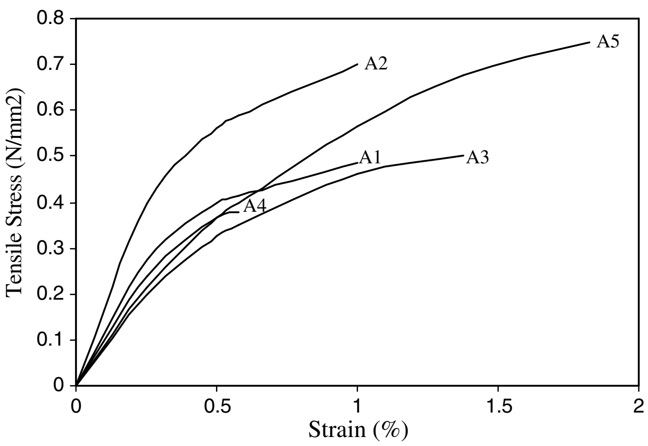

Fig. 7. Tensile stress–strain relation for nonfibrous adobes.

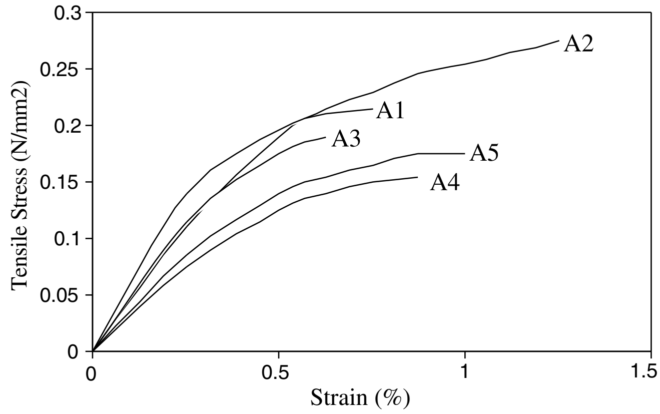

Fig. 8. Tensile stress–strain relation for fibrous samples that contain 0.6% fiber.

Table 8
Physical properties of fibrous and nonfibrous adobes prepared for tensile test

Series	W (by wt.%)	ρ (g/cm^3)	Shrinkage rate (by vol.%)
A1 nonfibrous fibrous	16.00 18.61	2.04 1.97	9.92 7.75
A2 nonfibrous fibrous	22.00 20.46	2.02 1.96	14.85 13.60
A3 nonfibrous fibrous	23.00 23.00	2.02 1.93	14.17 13.80
A4 nonfibrous fibrous	11.00 16.63	2.01 1.92	2.10 2.30
A5 nonfibrous fibrous	28.05 28.61	2.02 1.93	21.96 15.80

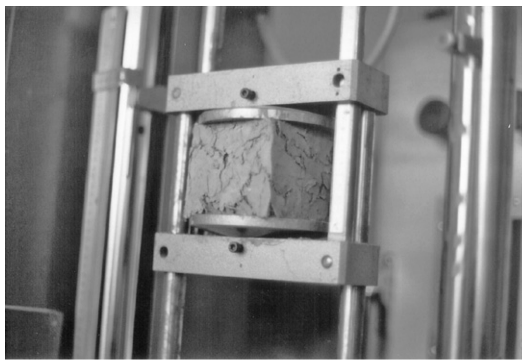

Fig. 9. The compressive test.

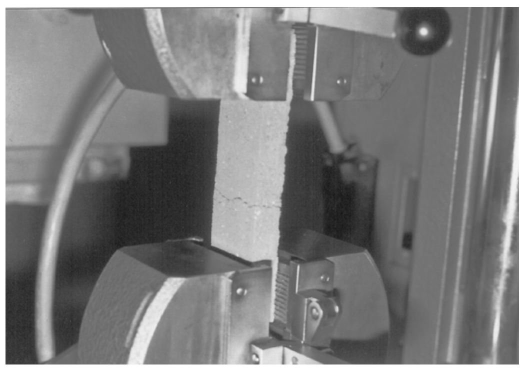

Fig. 10. The tensile test.

4. Results and discussion

The results of the experiments show that when the fiber contents of the adobes increase, the strain increases but the compressive strength decreases (Figs 1–5). Approximately same rate fiber content was chosen for every adobe type. Therefore, the comparisons gained more meaningfulness (Tables 2–6).

The results of compression tests obtained from the fibrous samples imply clearly three common points that;

1. For workability, as the fiber content increase, the water content needs to be increased since the fibers absorb the water [8].
2. The increase in the water content decreases the unit weight and so the strength. This situation is the same with nonfibrous adobes.
3. As the clay content increases, the plastic behaviors are seen clearly (Figs. 3 and 5). However, as the fiber contents increase, an early breaking is seen depending on quick drying. The material that dried quickly shows more brittle behavior (Table 5, Fig. 5).

Besides this, these fibrous samples also have a common behavior. This is the shrinking rates of drying materials and these are presented as volume contraction rates in Tables 2–6. The shrinkage rate is important during both production period and in application. This rate, especially in bricks, should not exceed 1% limit [13]. Moreover, when the shrinkage rate increases, the cracks increase and deepen. In the experiments, if shrinkage rate is less than 10% in volume, the cracks are not seen on the samples. According to this limit (10%), the dimension of cubic samples shrinks by 1 mm. This is in accordance with mentioned condition (1%). The experiments show clearly that as the fiber contents increase, the shrinkage rates decrease (Tables 2–6). The fiber content is an important agent on decrease in the strength; however, on the other hand, it decreases the shrinkage rate due to added viscosity and green strength [7,8,11]. Besides, increasing water content also has an effect on decrease of the strength. In addition, when the shrinkage (>10%) increases, that the surface begins to warp was seen.

According to the results of the experiments tested with nonfibrous adobes (Fig. 6, Table 7), in bearing and semi-bearing adobe structure elements, the clay content should be restricted between 10% and 20%. Moreover, it could be suggested that this rate should be between 13% and 17%.

In the fibrous and nonfibrous samples that were prepared for compressive strength test, workability water contents are about the same level. Therefore, comparison of these samples is appropriate. Adobe A1 showed 9% shrinkage rate for about 19% water content (Table 7). In addition, its compressive strength was about 2.3 N/mm^2 with 2.6% unit shortening (Fig. 6). For the fibrous sample in Series 1, the compressive strength risen barely to 1.0 N/mm^2 (Fig. 1) for 22% water content (Table 2). The reason of this decrease in the strength is, firstly, decrease in unit weight. Differences are seen clearly at other adobe samples. It should also be noted that because the clay content in A5 sample was very high (33%), the shrinkage rate remained as high as 12.8%, although fiber content is higher than 3% (Table 6). For nonfibrous of the same sample, because of same reason, the result of test shows 2.25 N/mm^2 of compressive strength with about 4.5% strain (Fig. 6).

The tensile strength tests also revealed very interesting results. Firstly, the strength–strain curve follow a smooth parabolic curve. Whereas, this tracing in the compressive tests was more sloping initially and the compressive strength was increasing slower. Except the adobe sample A1 that has less clay content, the other adobes' workability water content are kept equal or approximate values. The tensile strength in nonfibrous samples was greater than fibrous samples about two to five times. In addition, the additional water can be an effect on this result. The fiber content was constant and 0.6% in weight (Figs. 7 and 8, Table 8). Although the fiber content was very low, the fibers were stripped easily. Thus, this situation may be the reason for low tensile strength.

5. Conclusions

The results obtained from the uniaxial compression and tensile tests done with different fibrous and nonfibrous adobe samples are given below;

1. The compressive strength decreases by increasing fiber content; however, green strength increases.
2. The fibers that are circle section and hollow structure (straw) show flexible behavior under the loads and been stripped easily.
3. It is thought that an adobe mixture that has normal properties is provided with 13–17% clay content by weight.
4. For normal adobe mixtures, the fiber content should be restricted about 0.5% by weight.
5. The shrinkage rate increases by increasing the clay and the water content.
6. As the fiber content increases, the shrinkage rate decreases.
7. The tensile strength decreases by increasing the fiber content as compressive strength and unit length increase.
8. In tensile tests, the strength–strain graphs follow smooth parabolic line. On the other hand, this relation in the compression tests follows more sloping line initially.

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