On Extensibility of Fresh Concrete under Slowly Increasing Tensile Load

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Synopsis

The paper presents some results of experimental investigations on the extensibility of fresh concrete under increasing tensile loads when the speed of loading is varied.

The size of specimen was 4 cm × 4 cm in its section and 20 cm in its length. The tests were carried out in two series. One concrete mixture (w/c = 0.60, proportion = 1 : 2.85 : 2.55, slump = about 10 cm) was adopted in both cases.

1. When the concrete is stored in dry condition and is sustained under increasing tensile stresses from the 7th day after casting, the magnitude of the tensile strain increases almost inversely proportionally to the loading speed. The largest extensibility can be obtained for the lowest loading speed of 0.25 kg/cm^2/day, and the maximum total strain becomes about 4 times of that of usual short time test. Comparison between each strain corresponding to a load increment shows that the maximum strain appears in the first step of loading, that is, in the case of youngest concrete.

2. When the application of tensile load is started while the concrete is still wet, the maximum extensibility appears under a certain loading speed which is not so slow. The maximum value of total strain reaches to about 500×10^{-6}. The reason may be that a wet concrete has more extensibility than a dry concrete under tensile stresses. If the loading speed is too slow, the concrete may dry before the stress becomes high, and it may be understood that the strain does not increase so much even if the stress is increased sufficiently high later and the final strain does not show the highest value.

Introduction

It is already known that the strain of concrete has the tendency to increase when the stress is sustained for a long period. However, there are very few studies on the properties of concrete under sustained tensile stress. The present paper gives the results of some experimental investigations on the extensibility of fresh concrete under slowly increasing tensile stresses. The final object of these investigations is to find the sufficiently large extensibility, by which the cracks of concrete due to dry shrinkage could be avoided.

The tests were carried out in two series; for dry concrete and for wet concrete. The specimen had a section of 4 cm × 4 cm and a length of 20 cm. Special metal fittings were set on each end of the specimen as are shown in Fig. 1. The most part of these specimens

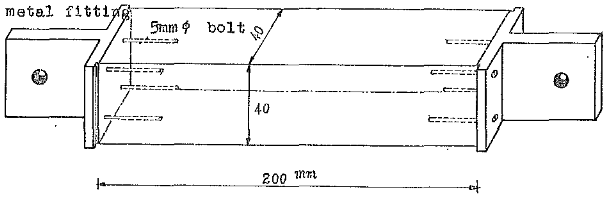

Fig. 1. Specimen

was used for the tension test and the other part was used for the measurement of free dry shrinkage in the same room air conditions.

Fig. 2 shows the sketch of loading apparatus. One end of the specimen was fixed to the floor and the other end was connected to the lever of loading apparatus, both through steel wire ropes and shackles, so that the bending moment on the specimen could be avoided. Sand bags, each weighing 400 grams, were applied by hand as the

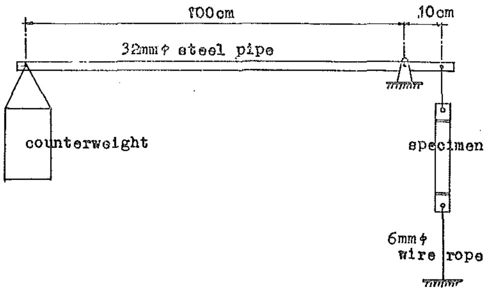

Fig. 2. Loading apparatus.

counterweight. As the lever-ratio was one to ten, one sand bag corresponded to the tensile load of 4 kilograms for the specimen.

Test Series I

Concrete mixture and preparation of specimen

An ordinary portland cement and Sagami River aggregates were used for concrete. The strength of cement is shown in Table 1. The aggregates were previously sieved in six grades and were composed

TABLE 1.

Water-cement ratio %	proportion	At 28th day	
		Modulus of rupture kg/cm²	Compressive strength kg/cm²
45	1 : 1	94.1	529
65	1 : 2	57.6	277

again in the rate shown in Table 2, for the purpose of equalizing the grading of aggregates as possible. The fineness moduli were 3.03 for the sand and 6.69 for the gravel.

TABLE 2.

Aggregates	Sand			Gravel		
Grading mm	0–1.2	1.2–2.5	2.5–5.0	5–7	7–10	10–15
Proportion %	67	23	10	3.4	27.6	69.0

Water-cement ratio was 60%, and concrete mix proportion was 1 : 2.85 : 2.55 by (weight) to have the slump of 10 cm.

The specimens were sealed in metal molds for two days after casting and then removed from the molds and stored in the room air of 20°C and 55% R. H. All the tests were performed under the same condition.

Loading speed

At first the load was adjusted to the tensile stress of 1.5 kg/cm² for each concrete specimen including its own weight and the weight of loading apparatus, and then the load was increased by the following increments and intervals:

(a) 8 kilograms per each 2 minutes (corresponding to 360 kg/cm² of tensile stress for concrete specimen per day)

(b) 16 kg. per each 15 minutes (96 kg/cm²/day)

(c) 16 kg. per each 2 hours (12 kg/cm²/day)

(d) 24 kg. per each 12 hours (3 kg/cm²/day)

(e) 16 kg. per day (1kg/cm²/day)

(f) 16 kg. per each 4 days (0.25kg/cm²/day)

Three specimens were respectively prepared for each test group.

All tests were started from the 7th day after the casting of concrete and the test (a) was supplemented at the 13th day, 19th day and 74th day.

Measuring method of tensile strain and free shrinkage

An electric-resistance strain-meter, made in Japan, was adopted for this purpose. The accuracy of this instrument is $(1\sim2)\times10^{-6}$ in the strain. Two small "wire strain gauges" which had the gauge length of 60 mm were pasted directly on the two opposite surfaces of a specimen. The surface must be dry, because the paste would be damaged by the alkalis of concrete. It was necessary to wait for 3 or 4 days after the removal of specimen from the mold in order to dry the concrete surfaces.

Test results

In these tests the data of free shrinkage was very important for the calculation of total tensile strain, because the observed values of strain were usually very small since the elongation was almost eliminated by the shrinkage.

The results are shown in Table 3 and Fig. 3.

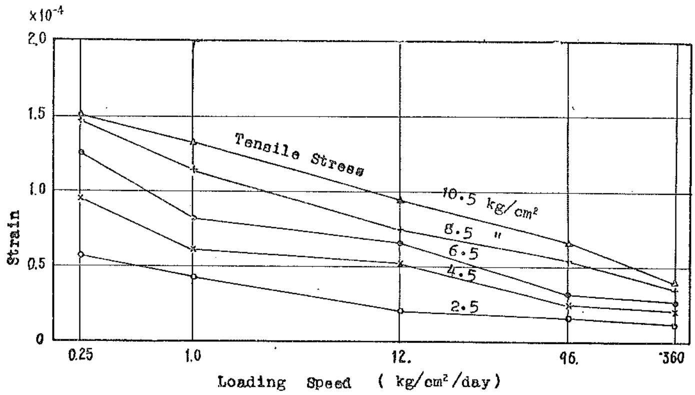

Fig. 3.

TABLE 3. Stress strain relation

group	loading speed kg/cm²/day	start of test day	strain in millionth at the stress (kg/cm²) of												maximum strain $\times 10^{-6}$	tensile strength kg/cm²
			1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5		
(a)	360	7th	8	12	18	22	27	29	31	39	42	43	48	·	70	11.8
			8	12	18	21	24	26	29	35	39	43	·	·	46	10.9
			8	12	17	20	24	26	28	35	39	·	·	·	41	10.1
		13th	8	12	23	30	39	44	52	60	72	74	·	·	93	11.7
			8	12	23	29	38	44	54	62	74	·	·	·	74	9.7
			8	14	23	29	38	44	53	60	69	73	85	97	112	12.5
		19th	8	14	23	29	39	44	53	60	70	78	87	·	100	11.9
			8	14	21	26	34	40	48	56	67	77	·	·	84	10.7
			9	14	19	26	36	40	50	54	64	71	·	·	71	10.5
		74th	9	15	23	29	34	41	47	54	61	68	76	93	93	12.5
			13	22	35	44	53	62	72	82	94	107	·	·	107	10.8
			11	19	30	38	46	55	64	73	·	·	·	·	78	8.8
(b)	96	7th	7	12	14	17	19	29	45	49	63	70	·	·	70	11.1
			6	11	16	18	21	31	47	49	58	68	·	·	68	10.7
			8	13	19	22	27	31	56	64	·	·	·	·	100	10.7
(c)	12	7th	·	29	48	51	65	69	·	78	102	108	·	·	121	10.5
			·	10	44	51	64	66	·	71	86	96	97	·	117	12.4
			·	23	43	55	67	67	·	74	90	102	·	·	123	10.9
(d)	3	7th	26	·	55	·	·	·	·	·	·	94	·	·	104	12.9
			17	·	80	·	·	·	·	·	·	99	·	·	156	14.7
			12	·	86	·	·	·	·	·	·	101	·	·	109	12.0
(e)	1	7th	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	·	·
			30	61	·	90	114	128	184	226	271	286	·	·	286	10.5
			19	42	·	68	83	89	116	120	121	140	164	185	185	12.5
			21	39	·	58	67	75	103	110	·	124	141	161	161	13.2
(f)	0.25	7th	(11)	(15)	(19)	(23)	(27)	(31)	(35)	(39)	(43)	(47)	(51)	(55)	·	·
			40	62	69	96	117	128	137	150	151	152	167	183	183	13.1
			40	57	65	80	97	102	112	120	120	122	134	139	141	15.3
			41	68	72	112	135	148	163	175	175	180	208	·	208	12.0

Note: Figures in the round brackets show the age of concrete after casting.

The accuracy of the tests is not so satisfactory, because the observed data of the tensile strain and the free shrinkage had both comparatively large deviation. However, the general feature of extensibility of fresh concrete can be suggested from the test results.

The total tensile strain increases considerably when the loading speed is slow. It seems in Fig. 3 of semi-logarithmic diagram that the strain corresponding to a certain load increment is almost inversely proportional to the loading speed, when the abscissa is graduated in logarithmic scale for loading speed. The difference of age of concrete is not considered in this figure, but it can be observed in the case of the lowest loading speed that the strains in lower steps of loading are larger than the strains in higher steps. The reason for this phenomena may be supposed that the younger the concrete, the larger the strain, or the extensibility becomes smaller when the concrete loses its water content by drying.

Test Series II

Scope of test

The test results of Series I suggested that the extensibility of concrete would further increase if the tensile load of low speed is applied from younger stage of concrete or while the concrete is still wet. Therefore, this series of test was started soon after the removal of specimens from molds.

The type of specimen, concrete mixture and loading apparatus were the same with those in Series I. The tests were performed in the room condition of 23°C and 50% R. H.

The starting period of test, the load increments and their intervals were selected as follows:

starting condition of test	load increment & interval
(A) The specimens were sealed in the metal molds for two days after casting the concrete. The test was started at the 4th day.	(a) 8 kg. per each 2 minutes (360 kg/cm^2 of tensile stress per day) (b) 16 kg. per each 12 hours (2.0 kg/cm^2/day) (c) 4 kg. per day (0.25 kg/cm^2/day)
(B) The specimens were sealed in the molds for 13 days. The test was started at the 14th day.	Same with the above (a), (b) and (c)

The test (a) was supplemented at the ages of 14 and 21 days for (A) group, and at the age of 24 days for (B) group. The number of specimens for each test was three in general.

Application method of strain gauge

The electric-resistance strain-meter was also used for the measuring apparatus. The "wire strain gauge" had been previously pasted on a piece of thin rubber plate with resin. Thus, it became possible to apply the strain gauge on the moist surface of fresh concrete body. Two pieces of rubber plates with strain gauges were sticked on the surfaces of a concrete specimen with a certain kind of plaster more than 12 hours before starting the test. The effect of those cementing materials on the length change was inspected beforehand, and it was found that the effect would be negligibly small after 12 hours.

Test results

The results of test are shown in Table 4.

(1) Short time test.

Test results are plotted again in Fig. 4.

In the test group (A) (the specimen was sealed in the mold for two days), the Young's modulus increases with the age of concrete, but the maximum value of total strain appears in the ages of 7～14 days (5～12 days after the removal from the mold). In the test group (B) (the specimen was sealed in the mold for 13 days) the total strain of specimen which was tested at the 24th day (11 days after the removal from the mold) shows a considerably large value. The strength and the maximum elongation may increase with the age of concrete when the concrete is held in moist condition. When the concrete is held in dry condition, however, the strength would not

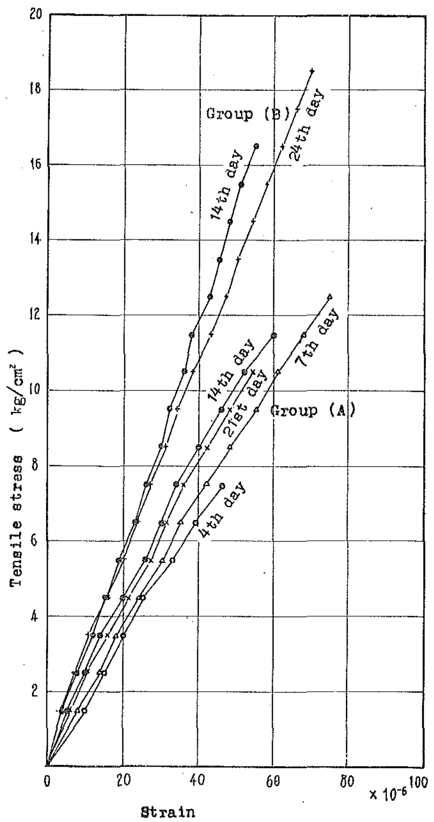

Fig. 4.

TABLE 4 (a). Stress-strain relation: short time test

group	loading speed kg/cm²/day	start of test day		strain in millionth at the stress (kg/cm²) of 1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	maximum strain $\times 10^{-6}$	tensile strength kg/cm²
(A) (a)	360	4th		11	14	18	23	30	37	44	·	·	·	·	·	·	·	·	·	·	·	57	9.0
				11	15	19	23	32	39	46	·	57	·	·	·	·	·	·	·	·	·	64	10.5
				8	13	20	26	34	41	48	·	·	·	·	·	·	·	·	·	·	·	57	8.5
				11	17	23	29	34	40	47	·	·	·	·	·	·	·	·	·	·	·	52	8.0
			mean	10	15	20	25	33	39	46	·	·	·	·	·	·	·	·	·	·	·	·	·
		7th		10	16	18	24	28	35	40	47	53	57	63	71	83	·	·	·	·	·	88	14.0
				8	13	18	23	29	36	43	50	54	60	·	·	·	·	·	·	·	·	68	11.0
				7	13	19	·	31	36	43	49	57	65	·	·	·	·	·	·	·	·	79	11.5
				7	13	17	22	30	33	41	46	51	57	·	·	·	·	·	·	·	·	59	10.5
				7	13	19	25	32	37	43	50	58	65	73	79	·	·	·	·	·	·	82	12.5
			mean	8	14	18	24	30	35	42	48	55	61	68	75	·	·	·	·	·	·	·	·
		14th		4	9	14	21	26	29	33	40	43	51	57	·	·	·	·	·	·	·	61	12.0
				5	10	14	20	26	30	35	40	47	·	·	·	·	·	·	·	·	·	52	10.0
				5	11	15	19	25	30	35	40	47	53	62	71	·	·	·	·	·	·	71	12.5
			mean	5	10	14	20	26	30	34	40	46	52	60	·	·	·	·	·	·	·	·	·
		21st		6	10	16	20	26	30	35	41	48	55	·	·	·	·	·	·	·	·	60	11.0
				6	10	16	21	27	31	37	43	48	52	55	60	·	·	·	·	·	·	60	12.5
			mean	6	10	16	21	27	31	36	42	48	54	·	·	·	·	·	·	·	·	·	·
(B) (a)	360	14th		3	8	12	16	19	23	25	29	31	35	38	43	45	48	50	56	·	·	63	17.5
				4	7	11	14	18	23	27	30	32	36	39	42	45	47	51	54	58	62	62	18.0
			mean	4	8	12	15	19	23	26	30	32	36	38	43	45	48	51	55	·	·	·	·
		24th		3	7	11	15	20	24	27	30	33	37	41	45	50	53	57	61	65	69	108	21.5
				5	9	10	16	20	23	28	31	35	39	43	48	51	56	60	63	66	70	76	19.5
				5	8	12	15	19	23	27	31	34	38	44	47	50	54	58	63	·	·	67	17.0
			mean	4	8	11	15	20	23	27	31	34	38	43	47	50	54	58	62	66	70	·	·

TABLE 4 (b). Stress-strain relation: Long time test

group	loading speed kg/cm²/day	start of test day		strain in millionth at the stress (kg/cm²) of																			maximum strain ×10⁻⁶	tensile strength kg/cm²
				0.5	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0		
(A) (b)	2.0	4th				(5)		(6)		(7)		(8)		(9)		(10)								
					150	160	226	231	337	341	373	370	447	449	515	524							524	12.0
					150	154	212	217	316	321	354	366	428	432									432	10.0
					152	160	217	226	362	366	359	373	448	452	518	526							526	12.0
			m		150	158	218	225	338	343	362	370	440	444	517	525								
(A) (c)	0.25	4th		(5)	(7)	(11)	(15)	(19)	(23)	(27)	(31)	(35)	(39)	(43)	(47)	(51)								
				167	288	367	375	383	401	411	426	439	448	441	433	440	The test was stopped.							
				170	244	302	326	336	346	354	323	338	354	358	355	361								
				161	258	363	377	371	372	384	381	391	410	401	403	405								
			m	166	263	344	359	363	373	332	377	389	404	400	397	402								
(B) (b)	2.0	14th				(15)		(16)		(17)		(18)		(19)		(20)								
					103	110	143	144	191	195	300	304	346	347	359	363	364	367	398	400	437	433		19.0
					108	117	142	146	192	194	317	318	348	349	355	359	382	376	400	400	413	414	503	20.0
					115	121	158	161	216	219	314	314	347	354	362	365	399	402	450	453			453	17.0
			m		109	116	148	150	200	203	310	312	347	350	359	363	382	382	416	418	425	426		
(B) (c)	0.25	14th		(15)	(17)	(21)	(25)	(29)	(33)	(37)	(41)	(45)	(49)	(53)										
				128	169	170	172	185	196	205	203	204	214	210			The test was stopped.							
				126	157	167	162	170	172	190	192	193	200	194										
				123	175	191	202	213	223	225	228	231	237	235										
			m	126	167	176	189	197	207	208	209	209	217	213										

Note: Figures in the round bracket show the age of concrete after casting.

only stop to increase, but also the extensibility would rather decrease. Consequently, it may be supposed for the short time test that the maximum extensibility of fresh concrete in the way of being dried condition would appear at a certain age which should not be so old.

(2) Long time test.

Fig. 5 shows the relation between the calculated tensile strain of concrete and the loading speed. At the first step of loading, the increment of strain is inversely proportional to the loading speed. Especially, the specimen of group (A) shows a large extensibility over 300×10^{-6} at the tensile stress of 2.0 kg/cm^2.

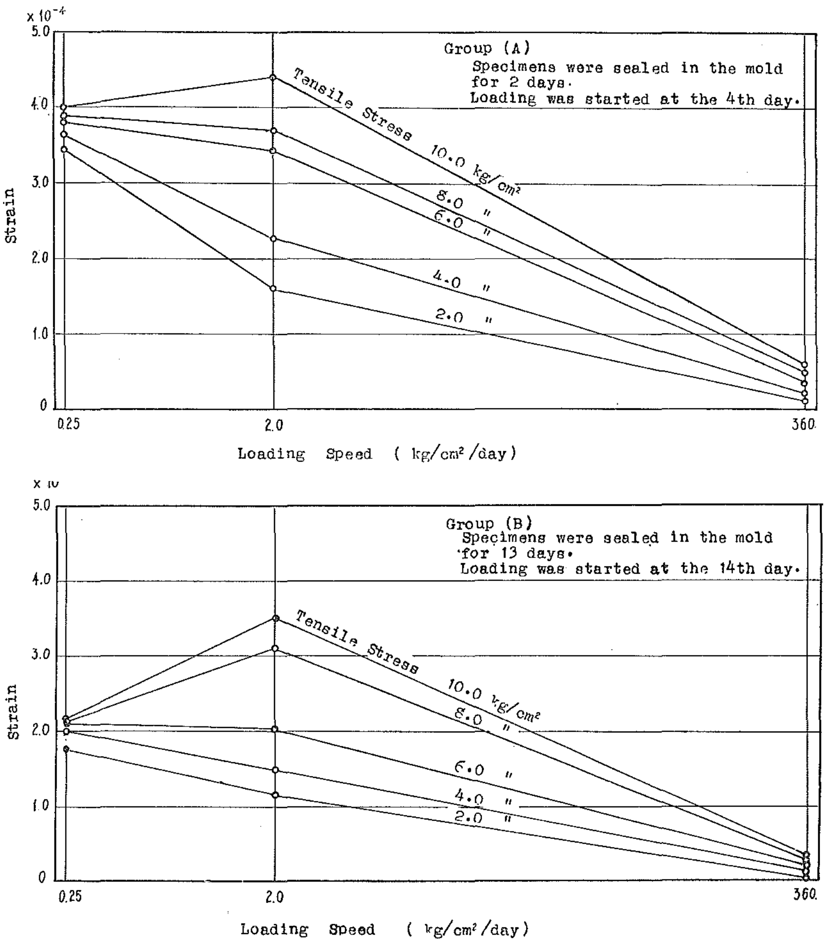

Fig. 5.

But in higher stress, the tendency of increasing the strain changes its feature. In this stage, the strain of specimen under the lowest speed does not increase so much, perhaps because of the considerable increase of the age of concrete, that is, because of the decrease of water content by drying. Since the tests under the lowest loading speed were stopped in half-way, the maximum strain corresponding to the strength of concrete could not be observed. However, it can be judged from the observed data that the maximum strain in this case should not exceed the strain under moderate loading speed.

On the contrary, the strain of specimen under the loading speed of 2 kg/cm²/day continues to increase until the stress is raised comparatively high. This phenomena is observed in both cases of group (A) and group (B), and the total strain becomes to exceed the strain of 500×10^{-6} for group (A) and it is over 400×10^{-6} for group (B). The ages of concrete, when these groups of specimens were failed by tensile stresses, were 9~10 days for group (A-b) and were 21~24 days for group (B-b). These ages almost coincide with the ages which are suggested as the most extensible period of drying concrete in the preceding item (1). This fact may mean that the tensile stress should be raised comparatively high while the concrete is most extensible, for the purpose of realizing a larger extensibility in long time test.

Conclusion

The auther has been interested in obtaining a sufficiently large extensibility of fresh concrete as an effective device of preventing cracks due to dry shrinkage. When the length of concrete is constrained to the original length, the dry shrinkage should cause a tensile stress in concrete member.

In this paper, the effect of slowing down the increasing rate of tensile stress on the extensibility of concrete was studied for small specimens, which had the section of 4 cm × 4 cm and the length of 20 cm. The tests were carried out in two series, and increasing rates of tensile stresses were varied between 360 kg/cm²/day (precisely 0.5 kg/cm² for every 2 minutes) and 0.25 kg/cm²/day (1.0 kg/cm² for every 4 days).

When the stress was applied after the concrete specimens were stored in a dry condition for 5 days, the increments of tensile strain were almost inversely proportional to the increasing rates of stresses. The slower the loading speed, the larger the strain. And it was observed that the strains in lower steps of stresses were larger than the strains in higher steps.

When the application of the tensile load was started soon after the removal of specimens from molds, the maximum extensibility appears under the moderate loading speed of 2.0 kg/cm^2/day. The reason may be supposed that the concrete, which is in the way to dry condition, has a certain period when the concrete is most extensible, and that a larger strain would be obtained when the stress is raised comparatively high during this period. If the loading speed is too slow, the concrete becomes too old while the stress is still low, and the strain would not increase so much even if the stress is raised sufficiently high later.

In these tests, the most extensible period was found to be about 10 days after the removal of specimens from molds. Of course, this period may differ depending upon the room air conditions and perhaps by the composition of concrete. Moreover, the dimensions of practical concrete members are larger than that of the specimen, but it can be expected also in this case that there would be a similar feature of concrete to have a certain period of the largest extensibility, and that the period would be retarded more than that of the specimen, because of the larger dimensions. A further extensive investigations must still be required before the definite conclusion about these natures will be derived.