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THE CREEP OF LAMINATED SYNTHETIC RESIN PLASTICS

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SUMMARY

The long-time loading strength of a number of lami-
nated synthetic resin plastics was ascertained and the
effect of molding pressure and resin content determined.
The best value was observed with a 30 to 40 percent resin
content. The long-time loading strength also increases
with increasing molding pressure up to 250 kg/cm^2; a
further rise in pressure affords no further substantial
improvement.

The creep strength is defined as the load which in
the hundredth hour of loading produces a rate of elonga-
tion of 5×10^{-4} percent per hour. The creep strength
values of different materials were determined and tabu-
lated (table 2).

The effect of humidity during long-time tests is
pointed out.

INTRODUCTION

If plastics are stressed so highly that they can be
used at about the same weight for construction as metal
unusually high deformations can occur at the comparable
stresses permissible for metals in aircraft design, de-
pending upon the kind of stress and the design of the
structural part. The deformations will be high because
of the low elastic modulus of plastics and the incipient
creep under protracted loads even for low stresses. The
effect of time on the deformation – the plastic and the
elastic portion – of laminated synthetic resin plastics
even at room temperature is already comparable to that of
metal structures at high temperatures such as do not occur
under normal service conditions.

The scope of experimentation on creep is not very extensive (reference 1).

A description of creep tests on laminated plastics prepared at various molding pressures and with different resin content, together with suggestions for improving the creep behavior of such plastics is given as follows:

Plastics under load manifest considerable creep even at room temperature, as exemplified in Müller's experiments with pure plastics (reference 2).

The deformation processes on laminated plastics are more complicated because of the existence of a very non-homogeneous and anisotropic structure.

EXPERIMENTAL SET-UP

The experiments were made on the fatigue-testing device shown in figures 1 and 2, which permitted testing of 16 samples at once. The specimens were loaded by weights (1) and lever (2) with an arm ratio of 1:6. The levers are mounted on ball bearings and carry balance weights with coarse and fine adjustment (3), (4). Clamping the test specimens in spherically mounted clamping heads (5) with wedge grips insures a centrally applied load. The shock-free application of the load is insured by the tension springs (6) and the lowering of the load by means of a spindle (7). The elongations were recorded with a Fuess cathetometer (fig. 1). The instrument rotates about a vertical axis and is disposed in the center with the test specimens arranged in a half circle. Its recording accuracy is ±0.01 mm. The arrangement of the clamping grips permitted deformation measurements with other strain instruments as well.

To maintain constant temperature (20° C) a thermostat mounted on a level with the specimens controlled an electric stove. In a similar manner a hygrostat and an electric water evaporation system equalized the differences in atmospheric moisture.

TEST PROCEDURE

The study included:

1. Paper-laminated plastics

a) DVL plastic, molded from 0.6 mm thick soda
   pulp sheets. Resin content: 9 percent,
   31 percent, and 44 percent (in relation
   to weight of plastic).

b) Plastics, commercial papier-mâché

c) Z3A plastics, molded from 0.25 mm thick im-
   pregnated paper sheets, 31 percent resin
   content

d) Z3F plastics, the test specimens being taken
   from a molded structural part of an air-
   plane.

2) Fabric-laminated plastics of cotton fabric
   weighing 66 g/m^2, resin content 22 percent,
   38 percent, and 51 percent.

The binder for the plastics under 1a) and 2 was phenol-
formaldehyde resin brushed on the resin carrier. Plastics
1a, 1c, and 2 were molded between 200×90 or 200×40 mm
platens in an 80-t press at 60, 200, and 600 kg/cm^2 mold-
ing pressure and 145° C temperature. The specimens, the
shape of which is shown in figure 3, were taken from 200×
90×1.2 and 200×40×1.2 mm plates for materials 1a, 1c, and
2, from 1000×1000×1.2 mm plates for material 1b, and from
a molded aircraft part for material 1d.

The measurements were made at 20 ± 1° C temperature
and 70 percent ± 1.5 percent relative humidity.

The elongations were measured with a cathetometer
(±1/100 mm) and in the low-load range with a dial pre-
cision gage (test length 50 mm, magnification 1:50).
Through the experiments the following values were deter-
mined.

1. Long-time loading strength in relation to

   a) Molding pressure

   b) Resin content

The tests lasted for 30 days. The long-time loading
   strength was defined as the stress which could
   be sustained for at least 30 days without failure.

2. Strain-time curves corresponding to the long-time
   loading strength.

The elongations were recorded during an 185-hour load
   period and subsequent 185-hour unloading period.

3. Creep strength.

The creep under load was observed for different
   stress during 185-hour, 500-hour, and 700-hour
   tests. After load removal the creep behavior was
   followed for a time corresponding to the loading
   period.

TEST RESULTS

Figures 4 to 7 give the time elapsed to cause failure
for paper-laminated and fabric-laminated plastics under
various stresses. The long-time loading strength defined
as the stress which is withstood at least 30 days without
failure ranges between 50 to 75 percent of the tensile
strength for a given material, depending upon resin con-
tent and molding pressure. All curves exhibit a marked
drop in stress within a comparatively short loading period.
For 2-day loading the strength of all the materials is on
the average nearly 40 percent lower than in a tensile
test with 800 $kg/cm^2/min$ rate of loading. After a 10-day
loading period no appreciable stress decrease is notice-
able.

1a) Long-Time Loading Strength in Relation to Molding Pressure

According to figure 8 the long-time loading strength
of Z3A increases considerably with increasing pressure
up to about 250 kg/cm^2, but a further rise in molding
pressure affords no marked improvement in strength.

1b) Long-Time Loading Strength in Relation to Resin Content

The long-time loading strength shows the same de-
pendence upon resin content as the breaking stress in
the tensile test with uniformly increasing load (refer-
ence 3) (fig. 8b). In both the paper-laminated and the
fabric-laminated plastics the strength increases with
increasing resin content. The best values range between

30 and 40 percent resin content, while an increase beyond
40 percent is followed by a drop in strength again.

The principal results are reproduced in table 1.

2. Strain-Time Curves for the Stress Corresponding to the Long-Time Loading Strength (fig. 9)

All the materials manifested at this load total elonga-
tions (1.2 to 2.5 percent) far in excess of the amount per-
mitted in engineering structures. The permanent strains
alone after 190 hours of loading exceed 0.2 percent. The
strain-time curves disclose a lasting decrease in the rate
of strain but without reaching zero. For the purpose of
answering the question as to whether the test specimens
break in finite time, the time-strain curves of figure 9
were replotted in a semilogarithmic coordinate system.
All the time-strain curves of figure 10 are concave toward
the strain axis, that is, danger of failure exists within
a finite time. But the elongation remaining upon release
of the load disappears within comparatively short time
according to figure 9.

3. Creep Strength

The definition of the creep strength postulates for
every material the knowledge of the rate of creep at a
given time. The evaluation of the time-strain curves for
determining the creep strength was carried out, using the
relations described by F. Gentner (reference 4).

In the determination of the creep strength two funda-
mental types of time-strain curves should be distinguished
(fig. 11). Following an initially similar concave course
toward the time axis the rate of strain of type (a) assumes
zero value in finite time, and the strain stops. On
curves of the type (b) the rate of strain decreases con-
tinuously without, however, reaching the value zero. So,
while curves of type (a) are in each instance located in
a safe range, the materials characterized by the time-
strain curves of group (b) can sooner or later lead to
failure, depending upon the speed of elongation.

Gentner shows how the aspect of the curves of type
(b), when plotted in a semilogarithmic system of coordi-
nates (time log on axis of abscissa) discloses whether
danger of failure exists in finite time.

Accordingly, time-strain curves do not result in
failure in a finite time interval.

1. If they are concave (hyperbolas) toward the time
   axis in the semilogarithmic system of coordi-
   nates

2. If they are straight (logarithmic curves)

3. If they start concave but subsequently tend to
   straight lines asymptotically (logarithmic
   curves).

The danger of failure in finite time exists, however,
for curves concave toward the axis of elongation (parab-
olas).

Figures 12 to 15 show the time-elongation curves of
synthetic resin plastics under different loads. Depend-
ing upon the magnitude of the applied stress, curves with
parabolic or logarithmic shape are readily distinguished.
In the long-time tests (700 hours, fig. 12) the applied
stresses produce a parabolic curve throughout the entire
time interval. These stresses would therefore produce
failure in finite time. The limiting stresses correspond-
ing to the creep strength and which satisfy the conditions
outlined under (3) precisely, are shown in figures 13 to
15.

Following the finding of these limiting stresses the
shape of the time-elongation curves was again determined
at a 5 percent higher load and it was ascertained that
these loads resulted in parabolic curves. Since a scat-
ter of ±5 percent must be allowed for synthetic resin plas-
tics, the stress value found initially determines the
creep strength with sufficient accuracy.

Next, the time-elongation curves were examined with
a view to predicting their subsequent shape from the creep
rate at specific times. Four specimens were tested, each
with different loads near the creep strength, and the time-
elongation curves (figs. 16 to 18) determined. The rate
of creep was determined for the time interval from the
40th to the 185th hour of loading and plotted against the
load (figs. 19-21).

Then the rate of creep for different loading periods
was obtained from these curves on the basis of a specified
load. For the previously found limiting stresses the rate
of creep in the 100th hour of loading amounted to about
5×10^{-4} percent per hour for the three different materials.

According to figures 16 to 18 it becomes apparent
that after 100 hours the rate of creep has decreased suf-

ficiently that this loading period is suitable for deter-
mining the creep strength.

On the basis of these considerations the creep strength
of laminated plastics was defined as the stress which in
the 100th to the 110th hour interval of loading produces
a rate of creep of 5×10^{-4} percent per hour. Furthermore,
the permanent elongation after 110th hour loading and sub-
sequent 24 hour relaxation must not exceed 0.2 percent.
This last condition is still met by the materials in ques-
tion even after a 190-hour load period. Since shorter
load periods yield less elongation, this condition is par-
ticularly well satisfied for 110 hour loading.

Table 2 contains the experimental values obtained.
For practical application the previously described method
is very useful for predicting the creep strength. Given
the rate of elongation permissible for a specified load
period the creep strength can be ascertained with three
to four samples; while the prediction of the creep strength
by the first method is less suitable because of the greater
number of tests and longer time required to determine the
limiting value.

Duplicate tests were made on one plastic with a view
to determining the amount of scatter to be expected in the
long-time tests; the results of an extreme case are shown
in figure 23. This scatter is primarily due to the fact
that the structure of laminated synthetic plastics is
microscopically neither homogeneous nor isotropic. Addi-
tional tests are necessary for a more accurate analysis
of the elongation differences.

TABLE 2.— CREEP STRENGTH OF VARIOUS PAPER-LAMINATED PLASTICS

Material	Tensile strength (kg/cm²)	Creep strength		In percent of tensile strength
		Gentner (kg/cm²)	On basis of 5×10^{-4} per- cent of rate of creep in 100th hour of loading (kg/cm²)	
Paper-laminated plastics, DVL	2038	720	715	30.1
Paper-laminated plastics, Z3A	2175	602	600	27.6
Paper-laminated plastics, com- mercial	1310	296	290	22.2

The tests disclosed that both the temperature and the atmospheric humidity affected the flow process of the plastics. Rising humidity augments the deformations, while decreasing humidity is accompanied by a shrinkage of the test specimens. Evidently, plastics are very susceptible to humidity effects in the stressed and strained state.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

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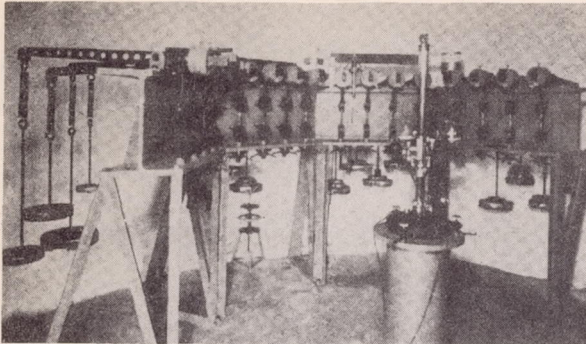
Figures 1 and 2.- DVL creep testing
apparatus for
plastics.
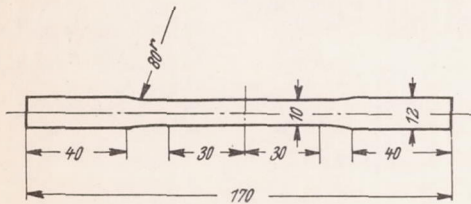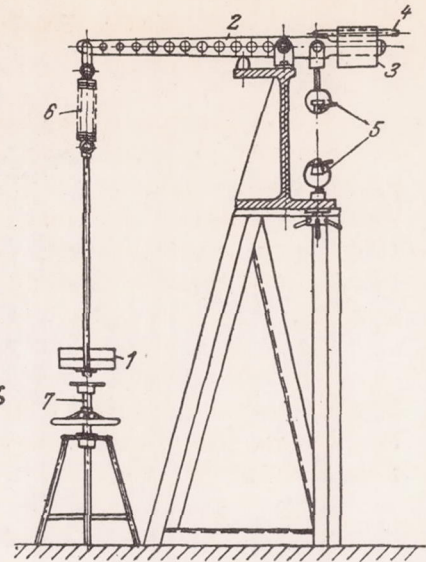
Figure 3.- Test specimen thickness
1.2 mm.

Figure 4.- Long-time
loading
strength of DVL
paper-laminated
plastics with different
resin contents.
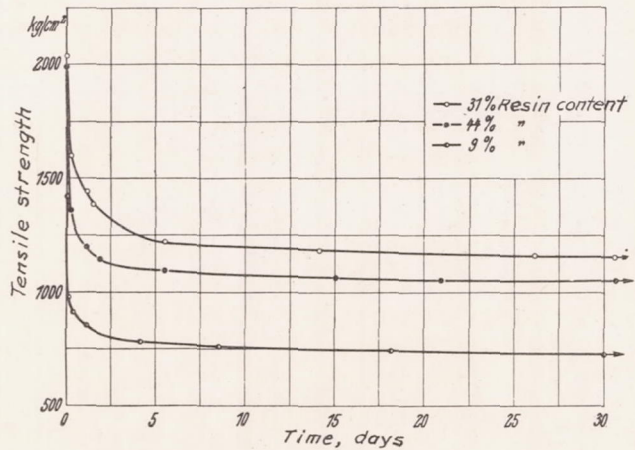
Figure 5.- Long-time loading
strength of paper-
laminated plastics Z 3.
(a) Paper-laminated plastics Z 3 A.
(b) Molded paper-laminated plastics.
(c) Commercial paper-laminated
    plastics.
(d) Paper-laminated plastics,
    Z 3 A No. 5690.
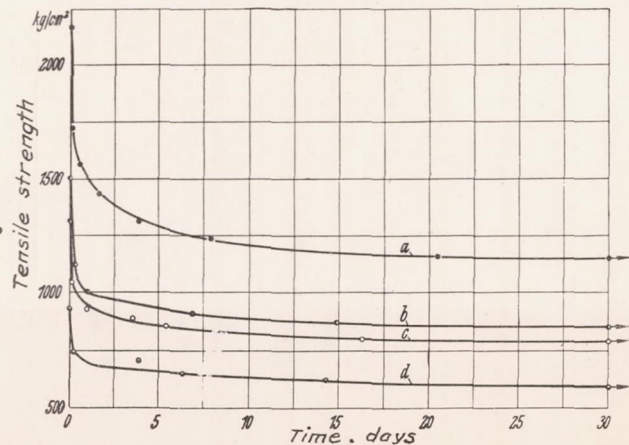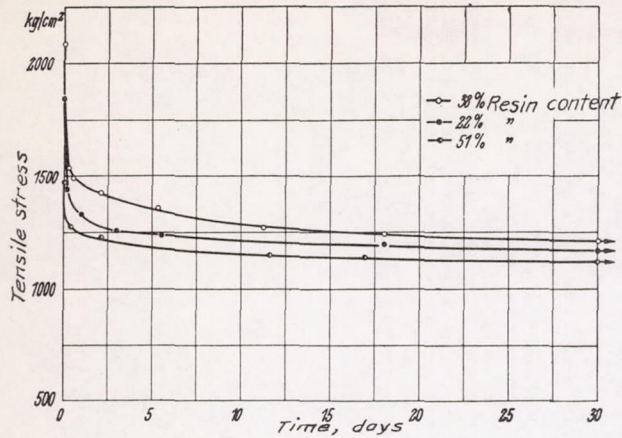
Figure 6.- Long-time loading strength of fabric-laminated plastics (DVL) with different resin content.

Figure 7.- Stress-time curves of paper-laminated plastics Z 3 A at different molding pressures.
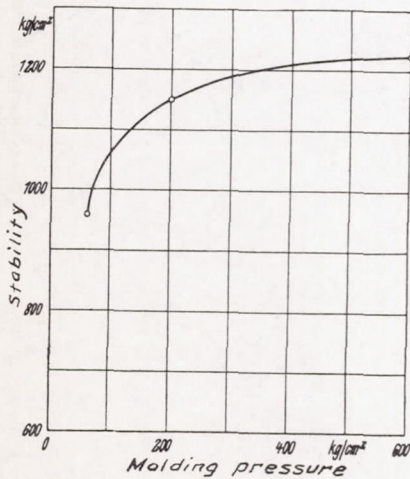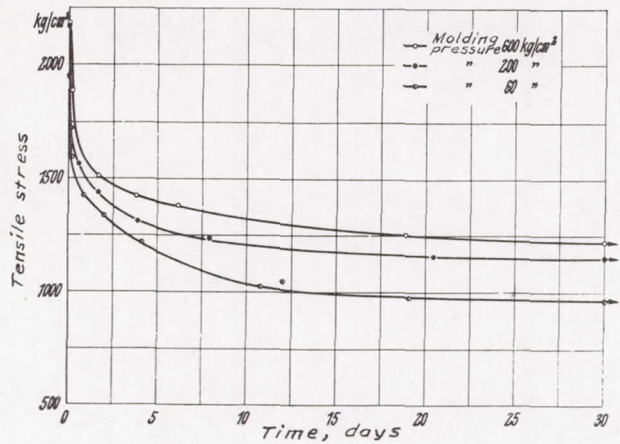
Figure 8a.- Long-time loading strength of Z 3 A as a function of molding pressure.
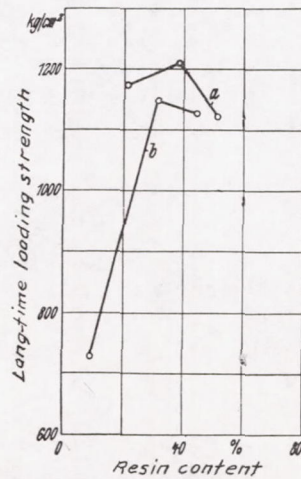
Figure 8b.- Long-time loading strength as a function of resin content.
(a) Fabric-laminated plastics (DVL).
(b) Paper-laminated plastics (DVL).
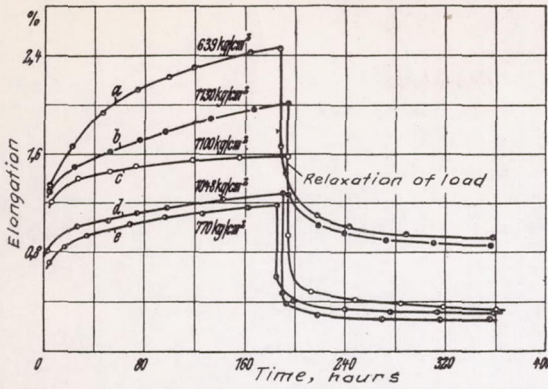
Figure 9.- Strain-time curves at
loads corresponding
to the long-time loading strength.
(a) Commercial paper-laminated
plastics.
(b) Paper-laminated plastics Z 3 A.
(c) Fabric-laminated plastics DVL.
(d) Paper-laminated plastics DVL.
(e)   "   "   "   airplane
structural part.
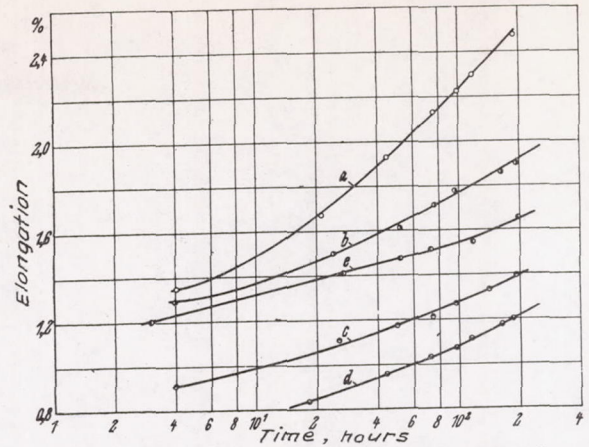
Figure 10.- Strain-time curves at
loads of around 50%
of that of the tensile strength.
(a) Commercial paper-laminated
plastics.
(b) Paper-laminated plastics Z 3 S.
(c)   "   "   "   DVL.
(d)   "   "   "   airplane
structural part.
(e) Fabric-laminated plastics DVL.
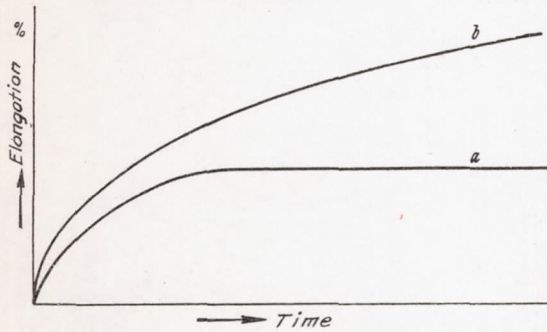
Figure 11.- Two possible types of
time-strain curves.
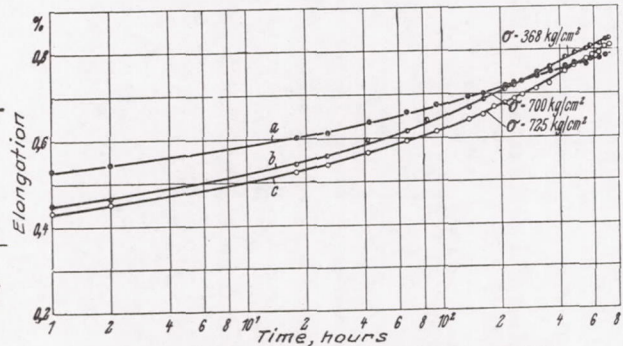
Figure 12.- Time-strain curves
(long time test).
(a) Paper-laminated plastics DVL.
(b)   "   "   "   airplane
structural part.
(c) Paper-laminated plastics Z 3 A.
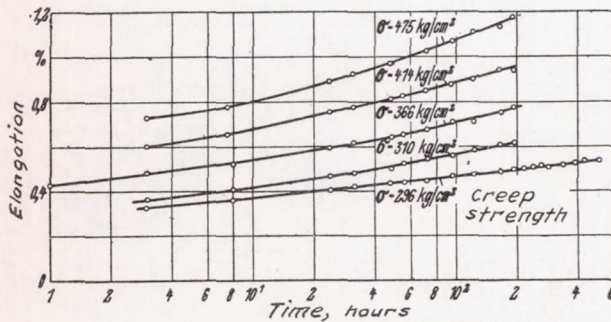
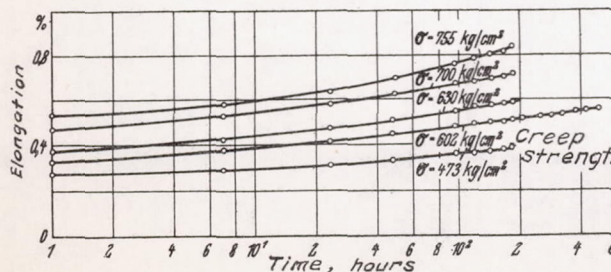Figure 13.- Time-strain curves of
commercial paper-
laminated plastics.

Figure 14.- Time-strain curves of
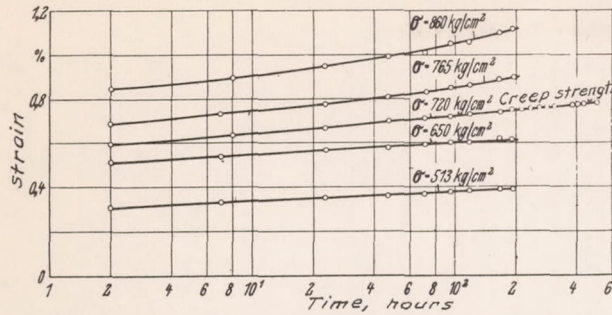paper-laminated
plastics Z 3 A.

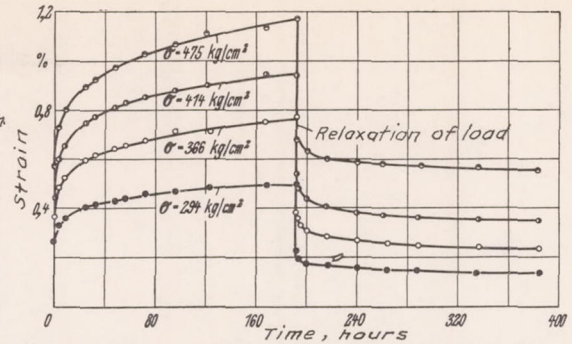**Figure 15.- Time-strain curves for paper-laminated plastics DVL.**

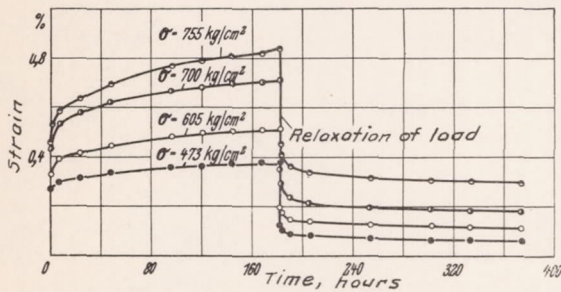**Figure 16.- Time-strain curves for commercial paper-laminated plastics.**

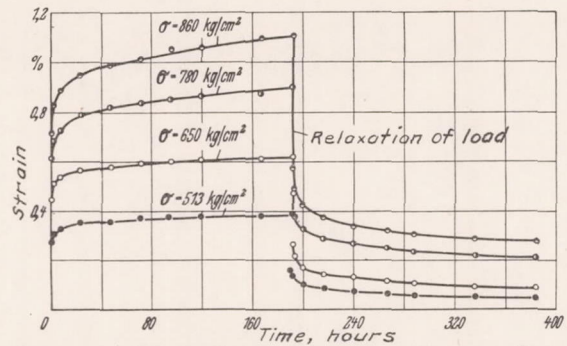**Figure 17.- Time-strain curves for paper-laminated plastics Z 3 S.**

Figure 18.- Time-strain curves for paper-laminated plastics DVL.
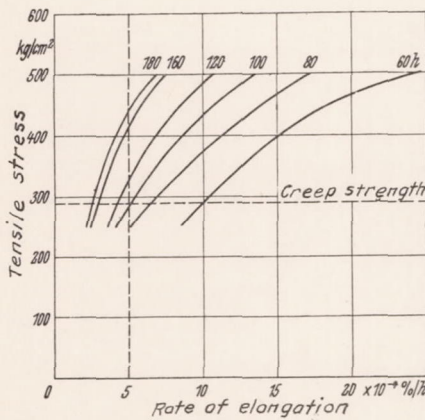
Figure 19.- Stress versus rate of creep at different loading times for commercial paper-laminated plastics.
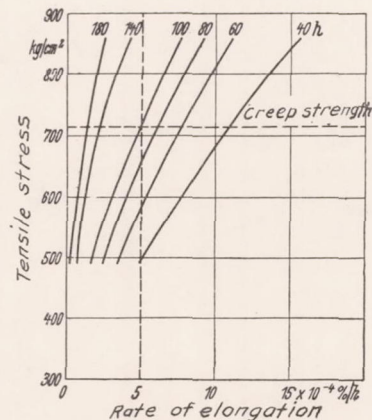
Figure 20.- Stress versus rate of creep at different loading times for paper-laminated plastics Z 3 A.
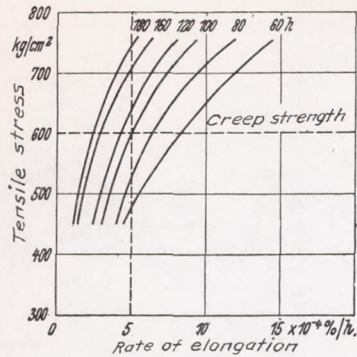
Figure 21.- Stress versus rate
of creep at
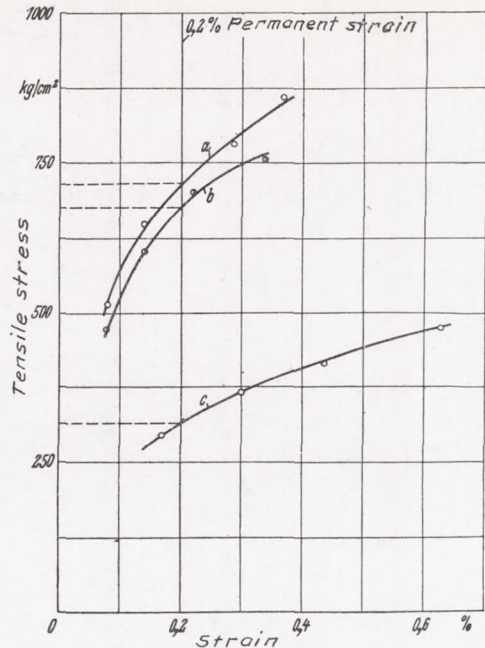different loading times for
paper-laminated plastics DVL.

Figure 22.- Stress remaining
after 190 hours
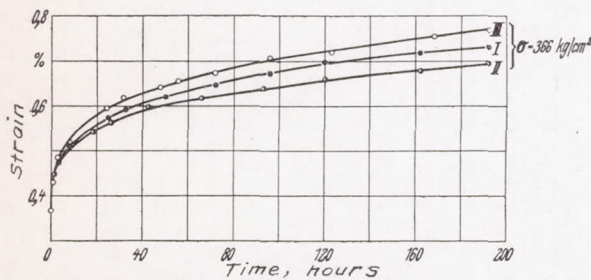loading followed by 24 hours
relaxation.

Figure 23.- Strain-time curves of
commercial paper-
laminated plastics for 3 different
specimens at the same load.

(a) Paper-laminated plastics DVL.
(b)　　"　　　　"　　　　"　　Z 3 A.
(c)　　"　　　　"　　　　" Commercial.

Table I. Long-time loading strength of synthetic resin plastics.

Material			Resin Content °/o	Molding pressure kg/cm²	Tensile strength kg/cm²	Long-time loading strength kg/cm²	Long-time loading strength in % of tensile strength
Paper-laminated plastics DVL	. . . . .		9	200	1420	725	51
»	»	»	31	200	2038	1155	56,5
»	»	»	44	200	1990	1050	53
»	»	Z 3 A	31	200	2175	1145	52,5
»	»	Z 3 A	31	60	1953	944	48
»	»	Z 3 A	31	600	2180	1230	56,5
»	»	Z 3 A No. 5690.	48	200	930	590	63,5
»	»	(Commercial) .	—	—	1310	790	60
Paper-filled plastics (Moulded) . .			—	—	1498	850	57
Fabric-laminated plastics DVL	. . . . .		22	200	1840	1170	63,5
»	»	»	38	200	2085	1210	58
»	»	»	51	200	1470	1120	76,5