TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 628

PLASTICS AS STRUCTURAL MATERIALS FOR AIRCRAFT

By G. M. Kline
National Bureau of Standards

Washington
December 1937

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INTRODUCTION

The current interest in the possibility of utilizing the modern plastic materials in the construction of aircraft can be traced to a passing reference to these products in a lecture by De Havilland (reference 23) delivered on April 15, 1935, to the Royal Aeronautical Society. Describing commercial aircraft built primarily of wood, he remarked, "Few will doubt, however, that metal or possibly synthetic material will eventually be used universally, because it is in this direction we must look for lighter construction." The plastics angle of this subject was treated at length by Langley (reference 4) in an article published in October 1935. Since that time considerable research work has been carried on in England to develop a reinforced plastic which would meet the requirements of the aircraft industry. That progress is being made in this direction is evidenced by the experimental results of de Bruyne, De Havilland, King, Walker, and others described in publications listed at the conclusion of this report. This is not the first attempt to utilize the superior fatigue characteristics, corrosion resistance, and fabricating qualities of plastics in aircraft parts. Caldwell and Clay (references 32, 33, 34, and 35) did the pioneering work on systhetic resin propellers early in the twenties. The airplane designed and built by Atwood, in which the wings and fuselage were each molded in one piece of extremely thin laminated films of wood and cellulose acetate, has been described in the literature (reference 16). Considerable development work of this type is also under way in those European countries which are dependent chiefly upon imported metals for their aircraft (references 25 and 40). The expanding applications of plastics for aircraft parts other than structural members have been reviewed by Pennington (reference 1), Stubblefield (reference 28), James (reference 37), Young (reference 2), and others.

Most of the experimental work on the use of plastics
in aircraft construction has been with the phenol-formalde-
hyde resin type. This material is the least expensive of
the synthetic resins and is thermosetting; i.e., it cures
during the molding process to an infusible, insoluble mass.
The thermoplastic materials, such as the cellulose deriva-
tives, and vinyl and acrylic resins, which can be alter-
nately fused and hardened by raising and lowering the tem-
perature, are probably too liable to cold flow to be use-
ful as structural materials. It is not considered to be
within the scope of this report to discuss the various
synthetic plastics that are available on the market or the
manner in which the properties of a given type, e.g., the
phenolic resins, can be varied over a wide range by suita-
ble modification of the chemical raw materials, catalysts,
or polymerization conditions. A chart of the properties
of commercial plastics and a list of trade names and manu-
facturers of these materials appeared in the October 1937
issue of Modern Plastics and serve as useful guides to the
diverse plastics available on the market today. Further
information on the classification and preparation of the
organic plastics is available in a circular of the National
Bureau of Standards (reference 44).

It is the purpose of this report to consider the me-
chanical characteristics of reinforced phenol-formaldehyde
resin related to the use of such a product as a structural
material for aircraft. The data and graphs which have ap-
peared in the literature on this subject are reproduced in
this survey as needed to illustrate the comparative behav-
ior of plastics and materials commonly employed in aircraft
construction.

This survey was made by the National Bureau of Stand-
ards with the cooperation and financial support of the
National Advisory Committee for Aeronautics.

DENSITY

The comparative average specific gravities of materi-
als commonly employed in aircraft construction and of re-
inforced phenol-formaldehyde resin are as follows:

Material*	Specific gravity
Stainless steel (18-8)	7.85
Chrome-molybdenum steel (heat-treated)	7.85
Aluminum alloy (24-ST)	2.80
Magnesium alloy (AM58S)	1.81
Aircraft spruce (Douglas fir)	.43
Reinforced phenolic resins	1.37

The advantage of low-density materials in permitting thicker wall structures is considered in detail by Shanley (references 17 and 18), and de Bruyne (reference 24). Tuckerman (reference 39) states that "in all cases (for a given modulus-density ratio) the wall with the greater thickness will have somewhat greater stability. Where the use of the heavier material would require extremely thin walls there is a very certain advantage, but of uncertain and variable magnitude, in the use of thicker walls of lighter materials, in some cases even with a somewhat smaller modulus-density ratio."

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*The values for specific gravity, tensile strength, yield point in compression, and modulus of elasticity given in this report were taken from the following sources: for stainless steel, chrome-molybdenum steel, aluminum alloy and aircraft spruce, from a paper by Alexander Klemin, entitled "Metal Airplane Construction" in Aero Digest, vol. 27, July 1935, pp. 43-45 and 112-113; for magnesium alloy, from a paper by Zay Jeffries, on "Light-Weight Metals in the Transportation Industry" in Metals Technology, of October 1936, and a bulletin on "Dowmetal," published by the Dow Chemical Company; for phenolic reinforced plastics, from papers by N. A. De Bruyne and M. Langley, listed in References and Bibliography, page 17.

STATIC STRENGTH

The comparative tensile and compressive strengths of various aircraft materials and selected reinforced phenolic products are as follows:

Material	Tensile strength lb./sq.in.	Compressive strength lb./sq.in.
Stainless steel (18-8)	185,000	150,000*
Chrome-molybdenum steel (heat-treated)	180,000	150,000*
Aluminum alloy (24-ST)	62,000	40,000*
Magnesium alloy (AM58S)	46,000	35,000**
Aircraft spruce (Douglas fir)	10,000	5,000
Phenolic resin - cotton flock filler	6,800	27,000
Phenolic resin - wood-flour filler	7,500	30,000
Phenolic resin - fabric filler	10,000	40,000
Phenolic resin - paper filler	19,000	30,000
Phenolic resin - cord filler	25,000	27,000

Although the values for the strength of the plastics are generally less than for steel and aluminum alloy, they are greater than for spruce, which has been quite commonly employed for the structural members of aircraft. The strength-weight ratio affords a more useful comparison for aircraft materials which are expected to develop their full strength before failure occurs in the member into which they are shaped. The strength-weight ratio, taken as the ratio of strength to specific gravity, is tabulated as follows:

*Yield point in compression.
**Yield point in tension. Yield point in compression is substantially equal to yield point in tension for wrought alloys.

Material	Tensile strength Specific gravity lb./sq.in.	Compressive strength Specific gravity lb./sq.in.
Stainless steel (18-8)	23,600	19,100
Chrome-molybdenum steel (heat-treated)	22,900	19,100
Aluminum alloy (24-ST)	22,100	14,300
Magnesium alloy (AM58S)	25,400	19,300
Aircraft spruce (Douglas fir)	23,300	11,600
Phenolic resin - cotton flock filler	5,200	20,600
Phenolic resin - wood-flour filler	5,500	22,100
Phenolic resin - fabric filler	7,200	29,000
Phenolic resin - paper filler	14,000	22,000
Phenolic resin - cord filler	18,700	20,100

It will be noted from these figures that the tensile strength-weight ratios of the ordinary laminated phenolic products are less than the values for steel, aluminum alloy, and wood, but that the phenolic product with cord reinforcement compares favorably with these accepted constructional materials. The phenolic products already lead in compressive strength on a weight basis. It is, therefore, apparent that a reinforced phenolic plastic can be produced which will have the necessary ultimate tensile and compressive strength characteristics to qualify as a suitable material for aircraft construction.

MODULUS OF ELASTICITY

In many cases the component members of an aircraft will fail by instability before the material can develop its full

strength. In these instances the strength of the member
will generally increase with an increase in the ratio of
the modulus of elasticity to the specific gravity of the
material, provided the outside dimensions of the member
and its weight are unchanged (reference 39). The compara-
tive average values for the modulus of elasticity and the
modulus-density ratio for the various structural materials
and reinforced phenolic products are as follows:

Material	Young's modulus (tension)	Young's modulus Specific gravity
	10^6 lb./sq.in.	10^6 lb./sq.in.
Stainless steel (18-8)	30	3.8
Chrome-molybdenum steel (heat-treated)	29	3.7
Aluminum alloy (24-ST)	10.4	3.7
Magnesium alloy (AM58S)	6.5	3.6
Aircraft spruce (Douglas fir)	1.3	3.0
Phenolic resin - paper filler	1.2	.9
Phenolic resin - cord filler	2.0	1.5
Phenolic resin - improved cord filler	5.9	4.3

The conventional types of laminated plastics are char-
acterized by low moduli of elasticity, and it was realized
very early (reference 7) that this relative lack of stiff-
ness was a major problem in the utilization of reinforced
plastics for structural purposes. With reference to metals,
Tuckerman (reference 39) notes that—"Density and modulus of
elasticity are stubborn properties of the material. The
most violent differences in heat treatment and mechanical
working, differences in treatment which change the strength
of a material by ratios as great or even greater than 10 to 1
can, at most, cause a change of a few percent in either
modulus or density." However, the stiffness of reinforced
plastics can be varied over a wide range by differences in
the type of reinforcement used and in the pressure applied
in manufacturing the plastic.

Cord reinforcement is much superior to paper or fabric filler if increased tensile strength and Young's modulus are desired. Figure 1 shows a stress-strain curve for a cord-filled phenolic plastic, according to de Bruyne (reference 24). The author states that "up to 6,000 pounds per square inch, hysteresis, but no 'elastic after-effect' is present; above this stress the strain rises gradually on applying the load and does not reach a final steady value until a few minutes after the time of application." A similar change in behavior of the material under compression was noted at a pressure of 6,000 pounds per square inch. Assuming a value of Poisson's ratio of one-third, this neutralizes the initial strain due to a lateral stress of about 2,000 pounds per square inch, which is the value of the molding pressure applied in preparing the plastic. De Bruyne notes that "the process of molding is one which we should expect would leave the resin in a state of compression relative to the fabric, because when the resin softens in the press it will experience a uniform hydrostatic pressure equal to the molding pressure and the fabric will be correspondingly extended. When the resin hardens it will keep the fabric in this state of tension. .... It appears as if the resin and cord reinforcement are able to act together so long as the lateral stress is less than the molding pressure. Above this stress the cord reinforcement shrinks away from the surrounding resin which then falls out of action...... When fabric instead of cord material is used, the stress at which elastic after-effect becomes appreciable is numerically equal to the molding pressure. Here, the resin, instead of being in continuous lengths parallel to the warp (as in the cord material), is broken up into a series of beads by the weft. These beads will clearly be pulled apart at such a strain as corresponds to the initial compression."

The effect of molding pressure on the behavior of a fabric-reinforced resin under stress, is shown in figure 2. Figure 3 illustrates the same effect obtained when threads were impregnated with resin, warmed to soften the resin, placed under tension, and kept under tension while the resin hardened by cooling. In each case the stress at which departure from Hooke's law occurs is the stress at which the resin was hardened. The details of the method by which the much higher modulus of elasticity was attained in the improved cord-filled phenolic plastic listed previously have not been published, but it is probable that improvements in both reinforcing material and method of processing were important factors.

RESISTANCE TO LONG-TIME LOADING

The reinforced plastics have been found to be comparable to wood in their resistance to fatigue. Figure 4 shows the results of static fatigue tests under tensile load made by the De Havilland Aircraft Company, Ltd. It is apparent that there is a static fatigue limit at about 75 percent of the strength to instantaneous load. Wood behaves in a similar manner as is indicated by the curve obtained by Graf (reference 43) shown in figure 5.

ENDURANCE LIMIT FOR ALTERNATING LOADS

The fatigue limit as determined by dynamic (Wöhler) tests is approximately the same as the static limit, as is evident in figure 6, which is based on the work of Gough (reference 42) and Cockcroft (see reference 24). De Bruyne points out that the behavior of cord-reinforced phenolic plastic is very different from that of metals because the specimen may continue to hold together for many millions of revolutions after a split has first appeared. The amorphous character of the material seems to prevent any violently progressive crack formation.

STRENGTH UNDER REPEATED IMPACT

De Bruyne (reference 24) compared the behavior of specimens of the same size and shape of the cord-filled phenolic plastic and various alloys under repeated impact tensile loads, using an Amsler repeated impact testing machine. The strength values obtained for the plastic were quite comparable to those for the metals and indicated the ability of the cord-reinforced resin to resist shock.

ENERGY ABSORPTION

Reinforced plastics have proved to be satisfactory for applications such as propeller blades, spinning pots for rayon manufacture, and gear wheels, in which they are subjected to severe alternating stresses. In order to investigate this property of plastics further, de Bruyne and

Maas (reference 15) made some measurements of the energy
absorbed under torsional oscillation. Their apparatus
was not suitable for making measurements of the damping of
materials with very small damping factors, but Iobike and
Sakai (reference 36) have studied materials of this latter
type. The results of these two investigations may be sum-
marized as follows:

Material	Strain energy absorbed percent/cycle	Investigators
Phenolic resin — fabric filler	24	De Bruyne and Maas
Phenolic resin — cord filler	20	Do.
Phenolic resin — paper filler	18	Do.
Mahogany	12	Do.
Walnut	12	Do.
Zinc	12	Do.
Zinc	11.7	Iobike and Sakai
Aluminum	1.10	Do.
Steel — 0.55 percent carbon	.24	Do.
Steel — 0.9 percent carbon	.17	Do.
Nickel	.021	Do.

This ability to absorb energy conveys many advantages
to materials characterized by superior behavior in this re-
spect. A material with a high value may be expected to
resist impact better than a material with low intrinsic
damping properties, since the energy of the blow can be
used up not only in creating strain energy in the material
but also in overcoming the internal friction. A material
with considerable intrinsic damping is less sensitive to

the effect of surface notches or sudden changes in cross
section than a material with a small energy absorption
(reference 38). Vibration is reduced to a minimum with ma-
terials of high energy absorption; for example, the tor-
sional damping of a metal monoplane is about one-fifth of
that of a wood monoplane wing. A disadvantage of excessive
damping is the considerable internal heating which may oc-
cur and which should be investigated in particular for
materials intended for use as propellers.

CORROSION

The resistance of reinforced plastics to corrosion has
been an important factor in promoting their extensive use
for many industrial purposes. Kraemer (reference 45), work-
ing in the laboratory of the Deutsche Versuchsanstalt für
Luftfahrt, has made a series of tests with phenolic resin
products reinforced with paper and fabric. In aging tests
out-of-doors specimens of the fabric-filled material had
undergone practically no loss in strength after 15 months.
Thin paper-filled specimens 1 millimeter thick had frayed
at the edges and showed a reduction in strength of 14 per-
cent after fifteen months. The originally smooth surface
of the majority of the specimens had become mat after six
months. Tests indicated that the flexibility of the spec-
imens was not affected by exposure for 15 months.

The resistance of these materials to salt water was
determined by immersion for 8 months in a stirred 3-
percent solution of common salt. Strength tests after 8
months showed that the paper-filled product had lost 12
percent of its original strength but that the fabric-
filled material remained unchanged. There was practically
no change in the appearance of the surfaces after being
immersed for 8 months.

Gasoline and oil had a negligible effect on the ap-
pearance and strength properties of plastics after a 10-
day period of immersion.

The maximum water absorption noted for a 24-hour pe-
riod of immersion was 0.85 percent for paper-filled spec-
imens.

The reinforced phenolic plastics are difficult to ig-
nite, and once ignited, burn relatively slowly and are
readily extinguished by a slight draft.

No results of tests on the stress corrosion of plastics were reported but it is probable that this effect is far less serious than for metals.

FABRICATION

Four methods of joining various sections made of reinforced phenolic material have been suggested, namely, cementing, riveting, bolting, and keying by interlocking joints. The synthetic resin cements have better aging properties and moisture resistance than the protein glues heretofore employed by the aircraft industry. Joints can be made between laminated phenolic resin plastics that will have a strength of 2,000 pounds per square inch or more, in shear. Greater strength may be achieved if the surface of the plastic is etched or sandblasted so as to expose the fibrous reinforcing material to the action of the cement.

With respect to the feasibility of riveting and bolting structures made up of reinforced phenolic plastic, de Bruyne has reported the following values for the bearing strength of the cord-filled product:

Diameter of bolt	Bearing strength
inch	lb./sq.in.
3/8	26,300
5/16	29,400
1/4	31,500
3/16	37,000

In general, the bearing strength of this material is more than five times that of spruce loaded parallel to the grain and thirty times that of spruce loaded perpendicular to the grain. Another factor involved in making riveted or bolted connections is the shearing strength. The low shearing strength of wood requires a large separation between the bolts. The greater shearing strength of the cord-reinforced plastic, 5,800 pounds per square inch along the cords, permits a much closer spacing of the bolts.

The method of keying by the use of interlocking joints has been used in metal aircraft construction and should also

be applicable to structures made from reinforced resinous products.

In the fabrication of aircraft today the labor costs are high relative to the costs of tools. If large sections could be molded in one piece, the labor costs would be reduced but the cost of the molds and presses would be very high. Such a change in type of construction would not be economically practicable except in the mass production of aircraft of a standard design. Langley (reference 19) suggests, therefore, that progress in the utilization of plastics in aircraft construction will be made by the gradual introduction of these materials into an otherwise orthodox structure, and that the early stages of this development will involve the molding of such small units as fins and rudders and the fabrication of the larger units from reinforced sheets and molded sections by conventional methods of jointing.

RESEARCH PROBLEMS

It is very difficult to outline specific problems on this subject because the exploration of the potential applications of reinforced plastics to aircraft construction is in its infancy, and is still uncharted. The development must include: the choice of resin and reinforcing material; the method of combining and forming them into a suitable product; the testing of such products to determine whether they possess the requisite physical characteristics; the design of structural members to take full advantage of the properties and fabrication possibilities of plastics; and the equipment for forming the separate sections and the technique of joining these sections to produce the finished aircraft. It is obvious that until more information is available on the first three of these items, namely, materials, processing, and properties of the reinforced plastics, it is too early to expect to make any considerable progress on the design and fabricating problems.

De Bruyne (reference 24) indicated in his paper presented before the Royal Aeronautical Society in January 1937, one possible approach to the improvement of the strength properties of plastics as follows. All synthetic resins are weak in tension and need reinforcement. If we could orientate the molecules so as to increase the number of secondary links or van der Waal's forces, we should be able to improve the mechanical properties. It is not im-

possible that such an effect could be achieved during the early stages of the reaction between phenol and formaldehyde by the use of electric fields. Numerous investigators have shown that it is possible to orientate a wide variety of organic molecules by electric fields. It is claimed in a recent patent that condensation of phenol and formaldehyde can be effected in alternating fields without the use of catalysts. It is not, therefore, too much to hope that we may obtain some control of the molecules in thermosetting resins so as to obtain products without reinforcement of a strength equal to that of cotton or silk.

The selection of a reinforcing material and the incorporation of it into the composition in such a manner as to utilize to a maximum its capabilities, has been the subject of considerable investigation already and will continue to claim the attention of workers in this field. The usual reaction to this problem is the thought that metal mesh, rod or wire should provide a satisfactory reinforcing medium just as it has been in the case of reinforced concrete. King (reference 9) has published the following remarks regarding this possibility of reinforcing the resin with steel or other metal wire.

"A little reflection will show that the division of loads in such a composite material is not structurally economical, even supposing real adhesion could be obtained between the materials to prevent slippage. Consider the simple case of a short resinoid strut reinforced with steel wires and compressed between end plates. In this example the load is supposed to be applied evenly to the ends of the specimen so that the tendency to relative axial movement may be neglected. Now since the elastic modulus of steel is approximately twenty times that for the resin, it is obvious that the stress in the steel will be correspondingly greater than that in the resin. The main function of the resin would be to stabilize the slender steel reinforcing wires, so enabling them to live up to a higher stress. Thus the contribution of the resin to strength (stiffness) would be 1/20 that for the steel, while its weight would be 1/6. Perhaps this will be clearer if each steel wire be considered surrounded by a sectional area of supporting resin twenty times that for the wire. Accordingly, the load which this will carry will be equal to that taken by the wire, but its weight will be 3-1/3 times as great.

"The proposal to use wire reinforcement near the top and bottom surfaces of beam members certainly deserves

very careful consideration, since it has been shown that
the low modulus, and consequently high deflection, of res-
inoid corded fabrics leaves much to be desired in the pres-
ent stage of development. An analogy is to be found in the
use of steel reinforcement for concrete beams, but in this
case it is necessary on account of exceptional weakness of
the concrete in tension. In the proposed application to
resinoid (reinforced) materials, the object is to increase
stiffness rather than strength, which has been shown to be
adequate. Suppose, now, the designer is disposed to allow
some additional weight, in order to attain greater beam
stiffness, the twin problems of slip and unequal expansion
still remain to be solved. As regards the first of these,
much depends on the size of wire and rate at which the load
builds up in the reinforcement by shear transference from
the surrounding mass of resin. Other things being equal,
greater strength would be obtained by the use of a large
number of very thin reinforcing filaments rather than by
using a few thick ones; for obviously the surface cross-
sectional area ratio would be greater and consequently a
better shear linkage would be attained. The loosening of
the bond between the resin and reinforcement, on account
of unequal expansion, is a matter requiring some consider-
ation. The coefficient of lineal expansion of synthetic
resin is approximately four times that for steel, but sup-
posing the former 'shrunk' onto the reinforcement, this
difference of expansion may not be serious over the small
temperature range which is likely to occur in practice."

It has also been pointed out by Walker that there is
good reason for avoiding, if possible, the use of metal
reinforcement because its use would introduce into the ma-
terial the poor fatigue qualities associated with matter
in a crystalline form.

The strength-weight ratios of various fibrous materi-
als which might be used as reinforcing agents are as fol-
lows:

Material	Tensile strength	Specific gravity	Maximum tensile strength / Specific gravity
	lb./sq.in.		lb./sq.in.
Cotton	40,000 - 62,000	1.55	40,000
Hemp	114,000 - 131,000	1.48	89,000
Ramie	99,000 - 114,000	1.52	75,000
Flax	85,000 - 156,000	1.46	107,000
Silk	50,000 - 63,000	1.36	46,000

The folding endurance of fibrous materials is also one of the advantageous features of textile reinforcements (reference 26).

De Bruyne (reference 24) found that cotton was one of the most satisfactory reinforcing materials for phenolic resin because it is readily impregnated and the elastic modulus of the thread is similar to that of the resin, so that when the composite material is strained, the adhesion forces between the resin and fiber do not reach high values. He also notes that the strength of the cotton thread never exceeds about 75 percent of the strength possible if all the fibers were parallel and prevented from slipping by some agency other than twist. A solid rod of regenerated cellulose should be a more suitable reinforcing agent than a thread of twisted fibers. His preliminary experiments showed that such coagulated material is not wetted by phenol formaldehyde. Considerable investigation has been carried on in this country recently on the impregnation of rayon with resins, and it is possible that a synthetic fiber could be developed which would be a satisfactory reinforcing material for phenolic resin.

The reinforced resinous products developed as a result of studies of raw material selection and processing mentioned previously should be submitted to tests to establish their behavior with respect to those physical properties of primary importance in aircraft design. The list of properties which the Bureau of Air Commerce uses in its A-N-C Materials Handbook may serve as a guide for this purpose. Their list is as follows:

Tension

> Ultimate stress
> Proportional limit
> Yield-point stress
> Modulus of elasticity
> Elongation

Compression

> Ultimate (block) stress
> Proportional limit
> Yield-point stress
> Column-yield stress
> Modulus of elasticity

Shear

    Ultimate stress
    Modulus of failure (torsion)
    Proportional limit (torsion)
    Modulus of rigidity (torsion)

Bending

    Modulus of failure
    Endurance limit

Bearing

    Ultimate stress
    Rockwell hardness
    Brinell hardness

    Specific weight

In the determination of these properties, it will be neces-
sary to consider the anisotropic nature of the reinforced
materials and to make the measurements along the various
axes accordingly.

    It has been observed (reference 9) that the stress-
strain curve for reinforced resins is dependent on the rate
at which the load is applied. When a stress is applied,
the strain does not instantaneously reach its maximum value.
The magnitude of this "elastic after-effect" increases with
the stress. De Bruyne notes that "this after-effect is
largely reversible and becomes very nearly so after the load
has been applied and removed four or five times. The ir-
reversible component of the creep becomes more noticeable
at high stresses. Even at 6,000 pounds per square inch,
however, in the cord-reinforced phenolic product, the irre-
versible component practically disappears after four or
five successive loadings and unloadings." He points out
that this strain is uniquely determined by the stress in
contrast to the "plastic hysteresis" of ductile materials
in which the strain is also a function of the time. Means
of raising the stress at which this creep becomes appreciable
have been reported by de Bruyne and Maas (reference 15).
This property is of prime importance with reference to the
use of reinforced phenolics for structural members of air-
craft and should be investigated in detail for any materi-
als which may appear to be promising in other respects.

It is also to be expected that the creep, endurance limit, damping, impact strength, and other properties of the phenolic reinforced plastics will vary somewhat with temperature. Therefore, the behavior of these materials should be studied at various temperatures within the range which might be expected to be encountered in service.

National Bureau of Standards,
     Washington, D. C., November 1937.

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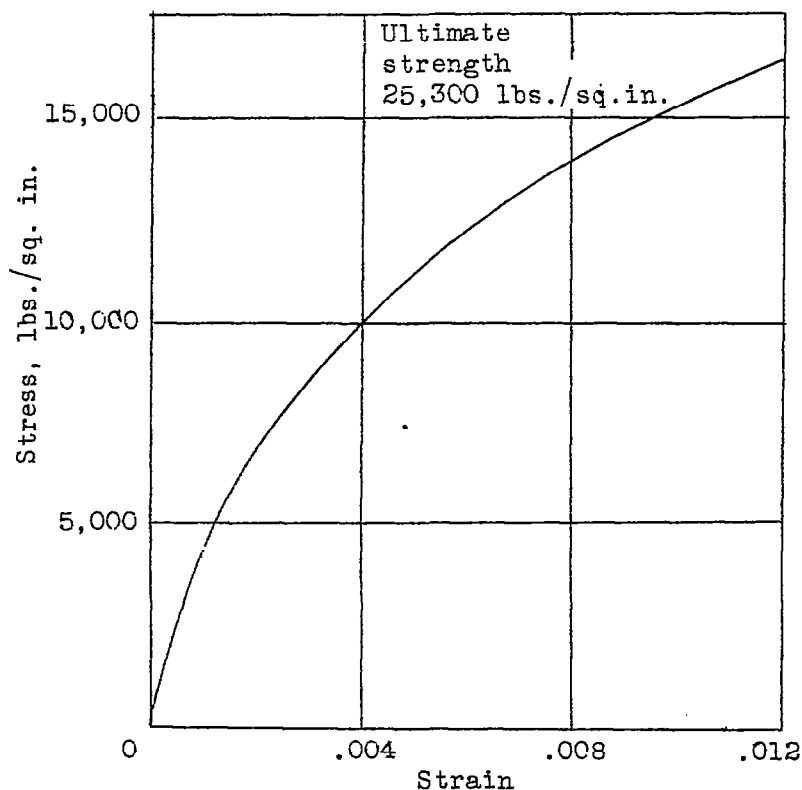
Figure 1.- Stress strain curve for cord
aerolite in tension.(Ref. 24)
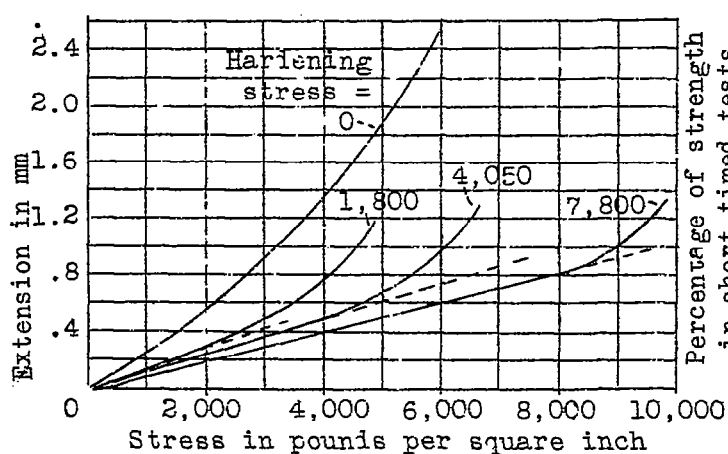
Figure 3.- Curves showing how the point of
departure from Hooke's Law is
directly dependent upon the stress on the
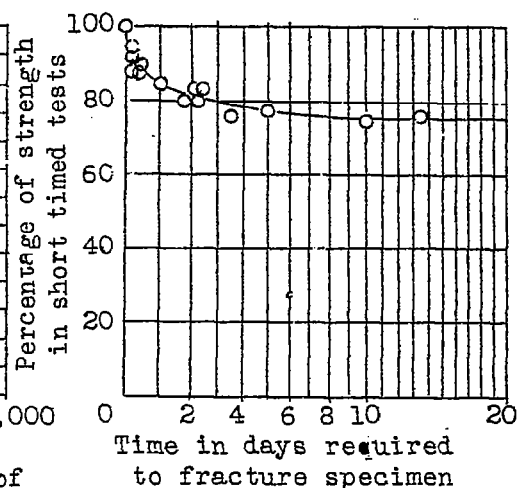material when the resin is hardened.(Ref.6)

Figure 4.- Static endurance
tests under tensile
load on reinforced synthetic
resin material.(Ref. 24)

Moulding pressure	1 ton/in.^{2}	2 tons/in.^{2}	4 tons/in.^{2}
E initial in tension	.70 x 10^6 lbs./in.^{2}	.83 x 10^6 lbs./in.^{2}	1.0 x 10^6 lbs./in.^{2}
E initial in bending	.76 x 10^6 lbs./in.^{2}	.89 x 10^6 lbs./in.^{2}	1.1 x 10^6 lbs./in.^{6}
Tensile strength	7500 lbs./in.^{2}	6470 lbs./in.^{2}	6030 lbs./in.^{2}
Density	1.46 grams/c.c.	1.46 grams/c.c.	1.44 grams/c.c.
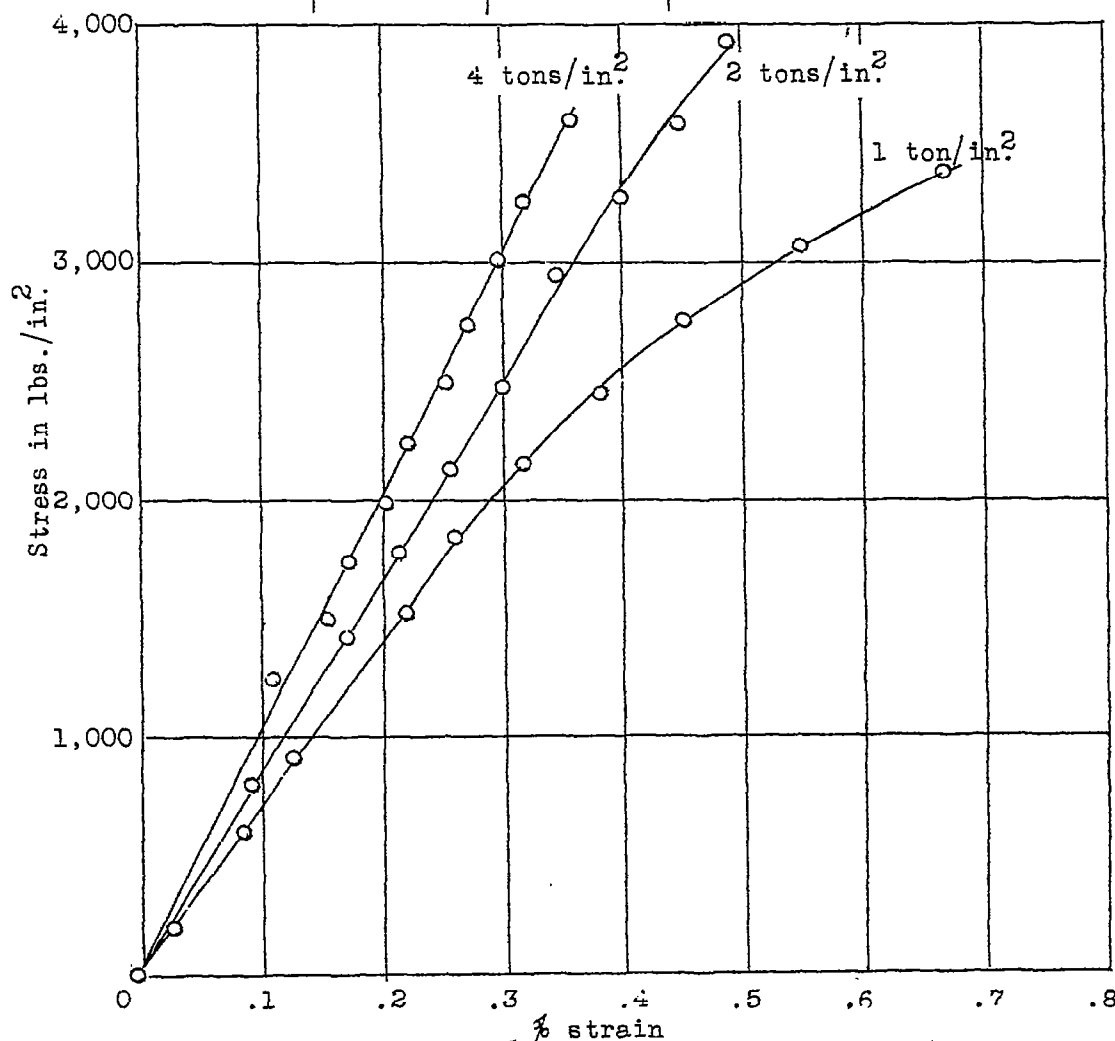
Figure 2.– Effect of variation of moulding pressure on some physical properties of urea formaldehyde resin reinforced with cotton fabric.(Ref. 24)
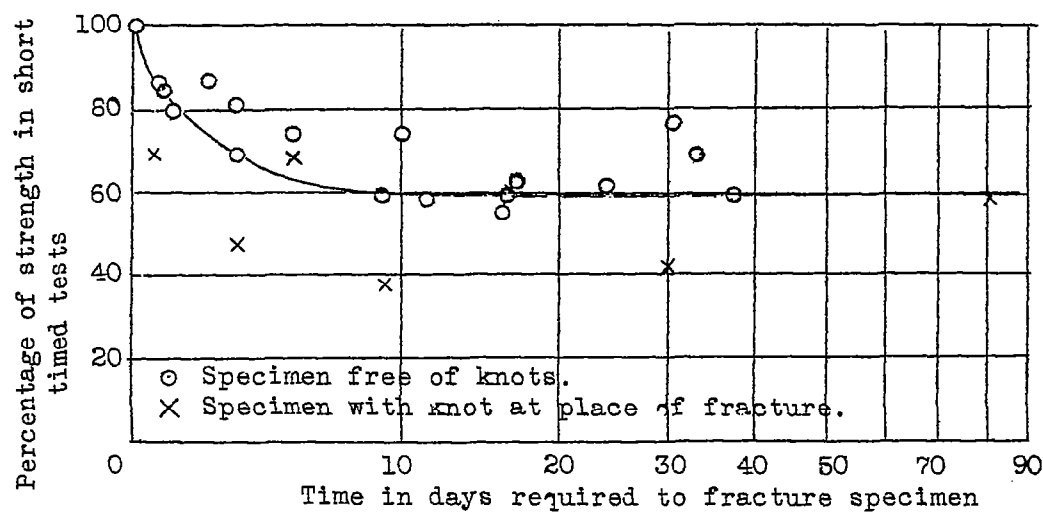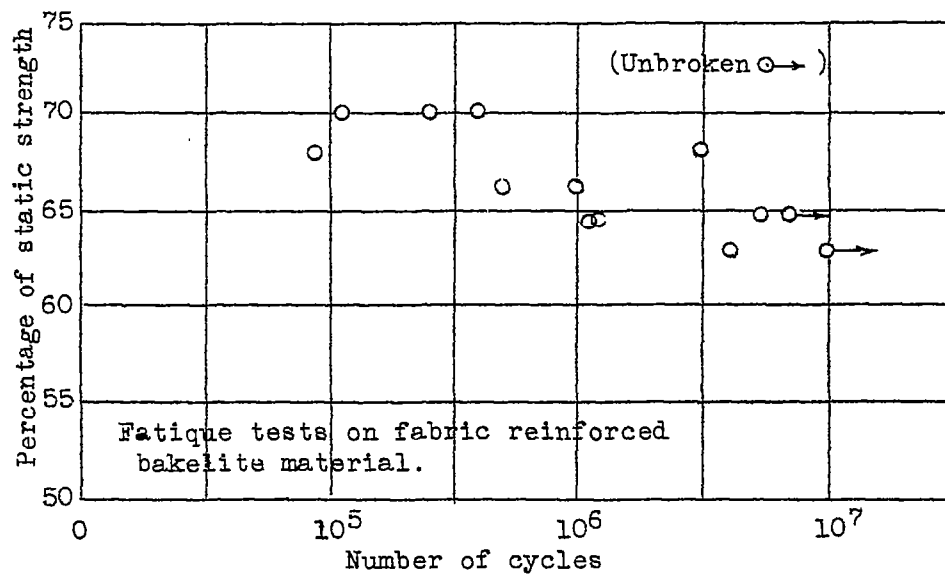
Figure 5.- Static fatigue tests on beams of pine.(Ref.24)

Figure 6.- Wohler fatigue tests on aerolite(coarse grain)
        (Ref. 24)