TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SYNTHETIC RESINS IN AIRCRAFT CONSTRUCTION - THEIR COMPOSITION, PROPERTIES, PRESENT STATE OF DEVELOPMENT AND APPLICATION TO LIGHT STRUCTURES

By K. Riechers

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By K. Riechers

In aircraft construction accurate knowledge of the strength properties and behavior of the construction material in actual operation is of essential importance. An attempt will therefore be made in what follows to give a brief review of the properties that have been attained with the synthetic materials with which we are at present familiar.

Obtaining the Synthetic Resins

The sources and method of preparation of the synthetic resins are schematically shown in figure 1. The starting materials for the synthetic resins with which we are familiar and that solidify in molding, are lime (C_aO), carbon and air - that is, raw materials which are obtainable in sufficiently large quantities to satisfy a demand even several times as great as the present one. Through the mutual action of the lime and carbon at high temperatures, calcium carbide is obtained and this combined with water yields acetylene. The latter is the starting material for a large number of products of the chemical industry, such as medicines, dyes, lacquers, solvents, fuels, synthetic rubber, etc. By polymerization of acetylene benzol is obtained and from the latter phenol, which is a component of synthetic resin.

From glowing carbon and steam carbon monoxide and hydrogen are obtained, and with the aid of pressure converted into methanol which serves as the starting point for formaldehyde, the second component of most synthetic resins. From phenol and formaldehyde, with the aid of condensating materials and catalytics, phenol resin is ob-

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*"Kunststoffe im Flugzeugbau - Ihr Aufbau, ihre Eigenschaften, heutiger Stand der Forschung und die Möglichkeit ihrer Verwendung im Leichtbau." Luftwissen, vol. 4, no. 8, August 1937, pp. 235-242.

tained which, with the addition of fillers, described below, yields either the molded phenol plastics or the laminated plastics.

Through the action of heat these phenol resins solidify or set, during which process the resin passes from the initial state - the so-called A or resol state - to the B or resitol state. The final product of the setting process is phenol formaldehyde in the C or resit state. Whereas in the resol state the resin is easily soluble in many solvents such as alcohol, acetone, etc., in the resitol state the resin is insoluble, does not fuse, and is highly resistant chemically. If the phenol resin, therefore, while in state A is combined with solvents (see fig. 1), it is possible to obtain lacquers, impregnating materials, and binders in liquid form.

The second large group of synthetic resins - the carbamide or urea resins - are obtained by the action of formaldehyde on urea in the presence of catalytic agents. (See fig. 1.) By the addition of certain fillers to the urea resin the amino plastics are obtained materials which find increasing application. The setting of phenol or urea resin under the action of heat is successfully utilized in gluing high quality plywood sheets. The general application of heat would be sufficient for the solidification of the synthetic resins if it were not for the separation of gas inside resulting in a completely porous material of no value for technical applications. It is only through the simultaneous application of pressure, which must amount to 300 kg/cm² (4,267.05 lb./sq.in.)and more, that suitable materials may be produced.

Fillers

The pure synthetic resin always is only a starting material for the final resinoid product. In only a few isolated cases - for example, for ornaments or jewelery is the pure synthetic resin itself an end product. In most cases the final synthetic material is obtained by combining the original resin with some other material, the so-called filler. (See fig. 2.)

By combining the synthetic resin with the filler, a product having properties not possessed by either of the two component materials is obtained. Thus, for example, the pure synthetic resins have too great brittleness and not sufficient toughness to find application as structural material subject to any appreciable stress. Similarly the fillers could never by themselves be employed as structural elements designed to take up forces. The properties of a synthetic resinoid depend on the kind of filler and the proportion of the resin as well as on various other factors, and this explains the large number of trade names used for each material. In the further fabrication of the synthetic material, only certain fillers can be used with a given fabrication process. Thus plates can be obtained by applying successive layers of paper or fabric sheets. To obtain a good plate it is necessary, however, to distribute the filler so that its individual parts flow together with the resin and so, for example, instead of fabric sheets or wood veneers, fabric cuttings or wood flour is employed.

According to the form of the filler the plastics may therefore be divided into laminated and nonlaminated or molded varieties. The laminated kind is mostly employed in the manufacture of sheets, tubes, and rods, while the nonlaminated kind is used in molded parts. It is, of course, possible to fabricate the molded plastics into plates or sheets or fabricate molded parts from laminated plastics. The latter today are of the greatest importance for the constructional parts of airplanes.

Types of Synthetic Resin Products

The laminated and molded resinoid products have been standardized into various types and classes. (See DIN 7701.) To the molded products belong the so-called phenol plastics, that is, the synthetic resinoid products whose base is phenol or cresol; for example, type S,T,M, and the amino plastics, type K - that is, synthetic materials whose base is carbamide resin (urea formaldehyde). The chief classes of the laminated resinoids are the resinoid papers of class II and resinoid fabrics of classes G and F with coarse or fine fabric inlays.

In addition to the "thermo-setting" resinoids there is the large, almost daily increasing, number of polymerized "thermoplastic" resinoids which, in contrast to the phenol plastics and amino plastics, may be fabricated in the soft state under the action of heat and may even be die cast. For airplane construction the thermoplastic resins are as yet of no importance since their properties hardly satisfy the requirements set upon them. They are employed mostly in electrical applications since their electrical properties are generally of a high order.

Possibilities for Constructional Applications

For light-structure application, particularly for airplanes, there remain only the molded and laminated synthetic resins. Of the molded products, only very few will be found at present suitable for application to airplane construction. Figure 3 shows the molded resinoid materials with their fillers that are used at present. The minimum strength properties of these plastics, according to the VDE specifications, are relatively low since these products have been developed for the field of electrical application only. As a result, the molded plastics found on the market are as yet unsuitable as regards strength for most purposes in airplane construction. Only the laminated resinoids have at present any chance of entering into competition with other structural materials.

There are two possibilities in the preparation of constructional parts from synthetic resins:

Following the method of wood construction the structural parts may be produced out of plates, tubes and rods through suitable glued joints, or molds may be used, in which case the filler is impregnated with synthetic resin and the synthetic resin sets during the molding process.

The first process has the advantage in that no expensive molds are required and the usual commercial "semimanufacturing" process may be used. As compared with wood construction there is the disadvantage, however, that the structural part is heavier although of higher strength $\left[\left(\frac{\sigma}{\gamma}\right)_{resin} < \left(\frac{\sigma}{\gamma}\right)_{wood}\right]$. The advantage of a single molding process is not utilized and hence also the advantage of laying the fibers of the filler in the direction of the stress. On the other hand, there is the impossibility in constructing airplane parts from synthetic materials of dispensing entirely with gluing. A considerable number of tests therefore have been conducted with the object of finding a suitable binding material. Among others, it was found that urea resin glue, kaurit, was quite suitable.

Figure 4 shows the strength of glued joint attainable with the two types of joints illustrated. In the case of synthetic resin paper the strength of the joint is comparable with that of good spruce, and in the case of the synthetic resin veneers, even considerably higher. The low strength of joint of synthetic resin fabrics, however, is rather surprising and is a phenomenon that has not yet found a satisfactory explanation.

The second process mentioned above is the only one possible for mass production but requires rather expensive molding apparatus for experimental purposes and, for producing reliable results, also a great deal of technical experience in this field.

Results of Investigations in and outside of Germany

It cannot as yet be predicted whether it is possible by intensive investigation, disregarding all desirable electrical properties, to improve the strength properties of the plastics to such an extent that a practically utilizable material for airplane construction will result. Figure 5 shows the strength coefficients for a synthetic resin with wood flour or shavings filler as prepared for use in electrical applications. For comparison the values for spruce as used in airplane construction are given in the last column. From comparison of the strength coefficients referred to the specific weight, it may be seen that pure synthetic resin does not at all meet the requirements while the phenol plastics with wood flour or cuttings filler approach some of the values for wood. (See σ_{-B} and $\sigma_{B'}$.) The elasticity modulus, however, is about 50 percent lower and the specific impact strength as much as 50 to 80 percent lower than the corresponding values for the spruce. This does not mean, however, that by suitable fillers and resin mixtures as well as by proper molding conditions it may not be possible some day to achieve great progress. Unfortunately, there exists no systematic investigation in this field. How great a change in properties of the material may be expected with changes in the component parts is shown by figure 6, where the change in the compression strength has been plotted as a function of the percent of filler. There is as yet, however, no answer to the question of just what happens when various resin or filler mixtures are used. Essentially the same questions may be asked in the case of the laminated resinoids. Here, too, the synthetic material industry has not received sufficient stimulus on the part of the construction industry or those interested in light structures to proceed with a broad and systematic approach to the solution of the problem. Therefore, it is only possible here to enumerate the characteristic properties of the synthetic materials that have been developed for application to the electrical field. From several tests that for some years have been conducted at the DVL, however, some conception can be formed of what increase may be expected in the mechanical properties to practical values applicable to structures.

Figure 7 gives the mechanical properties of the laminated plastics that are on the market today, namely, those of synthetic resin paper, synthetic resin fabric, and synthetic resin veneer and, for comparison, the properties of spruce and plywood. In the production of these materials the paper or fabric sheets or the individual wood veneers are impregnated with synthetic resin solutions- for example, bakelite A - and after drying (i.e., after evaporation of the solvent) are laminated in the manner desired and compressed under suitable pressure at the required setting temperature. All the strength coefficients rise considerably as compared with the values of the unlaminated materials. The ratio strength/specific weight, which is of special significance for light structures, not only attains the corresponding values for plywood but considerably exceeds them as well as those for airplane spruce. As compared with duralumin, the values still lie below although the tearing length, on account of the 50-percent lower specific weight, is the same. The elasticity modulus in the most favorable cases is onle one-third that of duralumin, while the impact strength cannot as yet be compared with that of the metal (fig. 8).

It should be remembered that these materials have been developed for the field of electrical industry only. Through a change in the molding pressure alone, as far as this can be done in present-day practice, it is possible to attain a considerable increase in the modulus of elasticity (fig. 9). By embedding suitable raw fibers, considerable increase in strength may be attained as well. Thus, in the tests conducted by the DVL, with fibers of agave, sisal, and aloe, a synthetic product was produced whose figure of merit σ/γ already attained the corresponding values for high quality metals (fig. 10). The modulus of elasticity is about three to four times as great as the modulus of the normal commercial synthetic product. In the case of one material, whose specific weight is only half that of light metal and whose elasticity modulus is a third to almost half that of the metal, a material has resulted that is capable of entering into competition as compared with present products. Since, for example, in computations on the stiffness in stressed skin construction, it is not the value σ/γ, but rather the magnitude $\frac{\sqrt[3]{E}}{\gamma}$ that is of chief significance, the comparison with other materials is even more favorable for the synthetic materials.

The values so far obtained do not by any means represent the highest attainable. Through the application of various devices in the process of manufacture of the plates further progress may be achieved as is shown by the most recent investigation results obtained at the synthetic resin laboratory of the "Aero Research" in England. If, for example, in the process of manufacture of the plates or other forms the fabrics used for the filler are subjected to an initial stress, an increase in the modulus of elasticity of from 25 to 30 percent is possible although at the expense of the tensile strength.

As a specially valuable property of the synthetic resins, there is still to be mentioned the great vibration property which has up to the present been investigated in isolated cases only. According to tests the ratio of the damping capacity of steel to that of synthetic resinoids is as 1:140. This property of the material is a very favorable one in airplane construction in that undesirable and often dangerous resonance vibrations are almost completely suppressed.

Endurance Strength

On the ability of the synthetic materials to withstand continuous static and dynamic loading, only meager data are available. In this connection, it is of interest to note that the synthetic material behaves better than spruce. Whereas the latter is ruptured under a continuous loading of about 60 percent of the short-time load, the synthetic resin fabric can bear about 78 percent of the short-time rupture load.

Bending Tests

As far back as five years ago, circular and plane bending tests were conducted at the DVL to determine the dynamic endurance strength. The circular bending tests (fig. 11) were carried out with the Schenk continuous bending machine and gave useful results only when certain special conditions were maintained. This also explains why similar tests elsewhere gave greatly deviating results, and the data of various investigators on the endurance strength of synthetic resins fluctuate between 35 and 65 percent of the static tensile strength.

More recent tests conducted at the Technical High School at Darmstadt give a ratio of 0.25 to 0.35, but this value should also be too high as shown by the tests recently concluded at the DVL. A difficulty in the determination of the endurance strength is the disorganization of the material during the tests - a phenomenon that has not yet been more closely investigated. It was therefore necessary to find a test procedure which would give a numerical indication of the start of rupture within the material optically not evident from the outside. A rod in the condition as supplied was subjected to a static bending load and the elasticity modulus determined within a load range of 0 to $\frac{1}{10}\sigma_{B'}$. The rod was next subjected to continuous bending tests beginning with a stress lying below the continuous strength limit anticipated. The elasticity modulus was determined after about every 50,000 alternating loadings and the load then increased by a small amount. At a definite stress the load began to decrease after the first 1,000 alternating loads. The number of 50,000 alternating loads was chosen since preliminary tests showed that the decrease in load after this number of loads was always below a certain order of magnitude.

The values of the elasticity moduli thus found are plotted on a coordinate system with abscissas giving the alternating stress and ordinates the modulus of elasticity, and a curve is thus obtained (fig. 12). Since the first point already gives the smallest drop in the modulus, the curve through the intersection with the horizontal passing through the points of equal modulus of elasticity will give, with a high degree of accuracy, that alternating load below which there is no disorganization of the material. This stress is the endurance strength limit.

Figure 13 shows the endurance limits that were obtained by this method for synthetic resin paper, synthetic resin fabric, and synthetic resin veneers.

Cell Wool (Zellwolle) in Place of Cotton Filler

Since up to the present, paper or cotton fabric and also linen fabric have always been employed the DVL, working in cooperation with the industry, sought to exchange the cotton for "cell wool" and the results of these tests are presented on figure 14 and show that not only a small addition but even a 100-percent cell-wool content as filler may be used to advantage.

Previous Tests on Constructional Parts

For some years tests have been conducted by the DVL with the object of applying the synthetic resins to aircraft construction. A few years ago a model spar was constructed (fig. 15) containing a whole series of glued surfaces. On account of the difficulty experienced at that time in efficiently gluing synthetic resins, it was found impossible to produce failure of the spar in bending without at the same time producing a slippage of the glued surfaces (fig. 16). It was therefore necessary to reinforce the binding of the glued surfaces with wood screws. A spar of this type had about the same rupture load as a wooden spar of the same weight that was constructed for comparison, yet the bending was about 40 percent greater. To what extent this small stiffness should be attributed to the rather poor joining of the glued surfaces, will not be gone into here.

In another test the rudder unit of a He 45 was constructed of synthetic resin instead of light metal. Again it was seen on loading the unit (the tests were carried out at the static testing division of the DVL) that the stiffness of the synthetic resin structure was considerably lower than that of light metal. The method of construction, however, did not do justice to the properties of the synthetic product since, in imitation of wood construction, pipes, angles, sections and plates were joined to one another instead of having the entire rudder, or at least parts of it, made of one piece.

Present Application to Aircraft Construction

What actual application has been made up to the present of the synthetic resins? In the manufacture of high quality plywood, even out of beech, synthetic resin glues only are admissible. Recently, kaurit has entered the field as a glue in the manufacture of plywood.

A step further in the combining of extra thin wood veneers with synthetic resins, are the synthetic resin veneers, listed on figure 17, which are already manufactured in large quantities and used as materials for bearings and pinions. Since these materials, according to experience gained by the DVL, may be reliably glued by means of kaurit and combine the good properties of both the wood and the synthetic resin, it may be assumed that they will one day find application to parts subject to high stress.

Synthetic resins are used also for such applications where other materials were found to be inferior on account of too high specific weight, danger from fire, manufacturing difficulties, or similar reasons. The application of the synthetic product was limited, however, to constructional parts not subjected to any appreciable mechanical stress and the failure of which would not endanger the aircraft. Board instruments have for years been provided with synthetic resin casings instead of the light-metal casings formerly used. The unpleasant characteristics encountered in the touching of two materials of different electric potential in screws, shut-off cocks, junction boxes, etc., were all eliminated at one stroke when the synthetic resin was used.

In none of the above cases was the synthetic resin product ever part of a force-transmitting structure. That synthetic resins are very well suited, however, for structural parts of maximum mechanical stress is shown by the micarta propeller that has been used for years and whose manufacture in modified form has been resumed by the De Havilland works (fig. 18). Whether or not propellers will be manufactured out of synthetic products, depends entirely on the number of units the market will absorb since a small demand can never justify the cost of the molds and mechanical installations of a micarta plant. It may be expected that with the use of the embedded sheets for controllable propellers and with the attainment of desirable simplicity and uniformity of propeller types, extensive application of the synthetic resins in this field is entirely probable. The synthetic product has already been used as a structural material in a highly stressed member in German airplanes. A factory in Hanover, for example, has developed an adjustable hub of laminated synthetic resin for an SH 14-A motor Figure 19 gives the values of the ststic properties of the material used. Dynamic oscillation tests gave surprisingly good results on this hub. Other factories of the industry are busying themselves with the development of certain airplane structural parts that could be turned out in large quantity. If the specific properties of these newer working materials are properly considered and the mode of construction of the materials correspondingly suited, it is to be expected that the chances of success in their application will be considerable. The greatest danger to which the application of these new construction materials is exposed is still to be found in prejudices, false applications, and designs not suited to the material. It is too early as yet to picture a larger structural member, for example, a wing as being constructed entirely of plastic material, yet it is certain that the next few years will see an extensive application of the synthetic resins in aircraft construction since in all industrially developed countries, this problem is being most energetically attacked.

Translation by S. Reiss,
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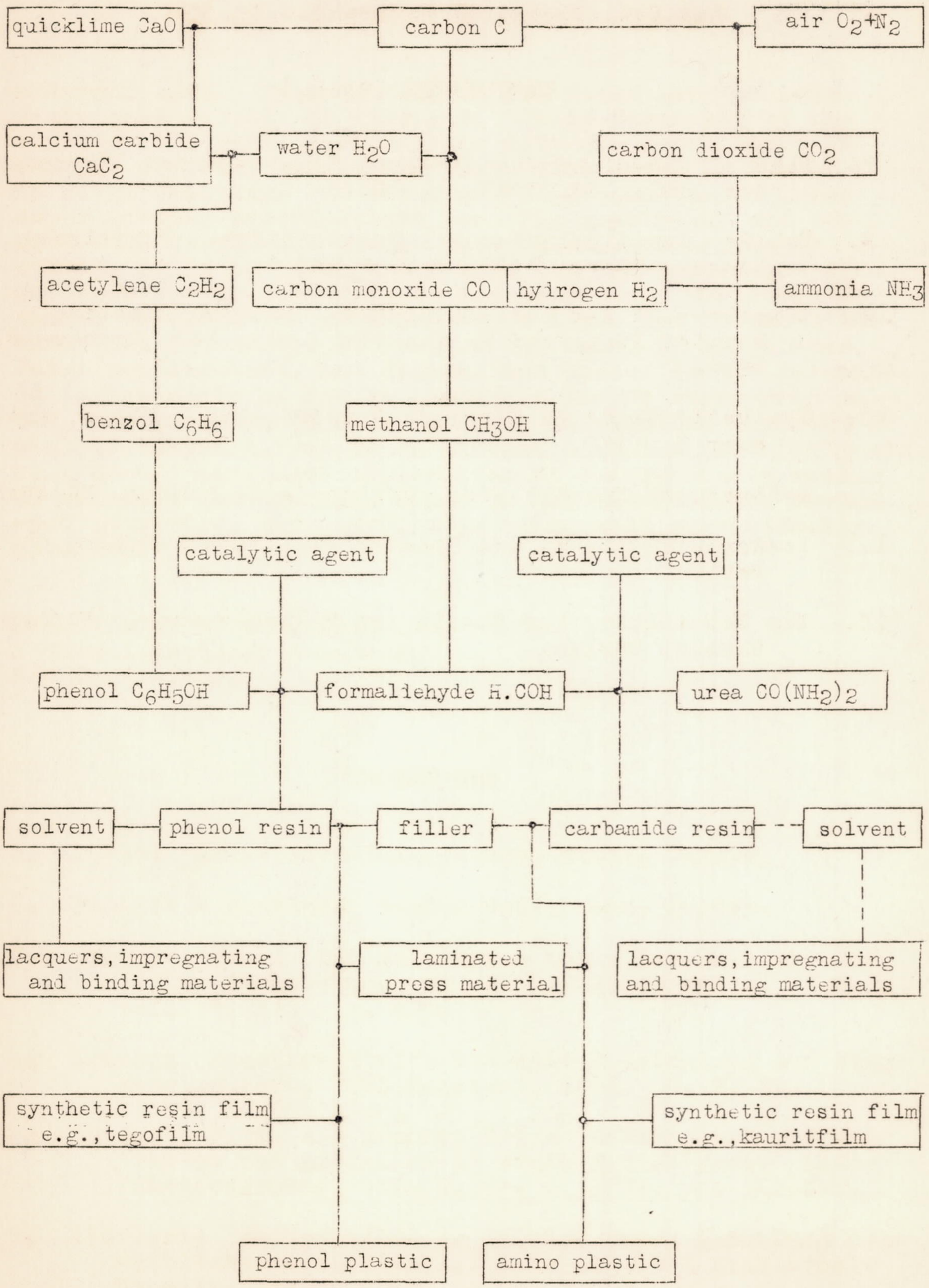


Figure 1.- Scheme of synthesis of phenol and urea synthetic resins.

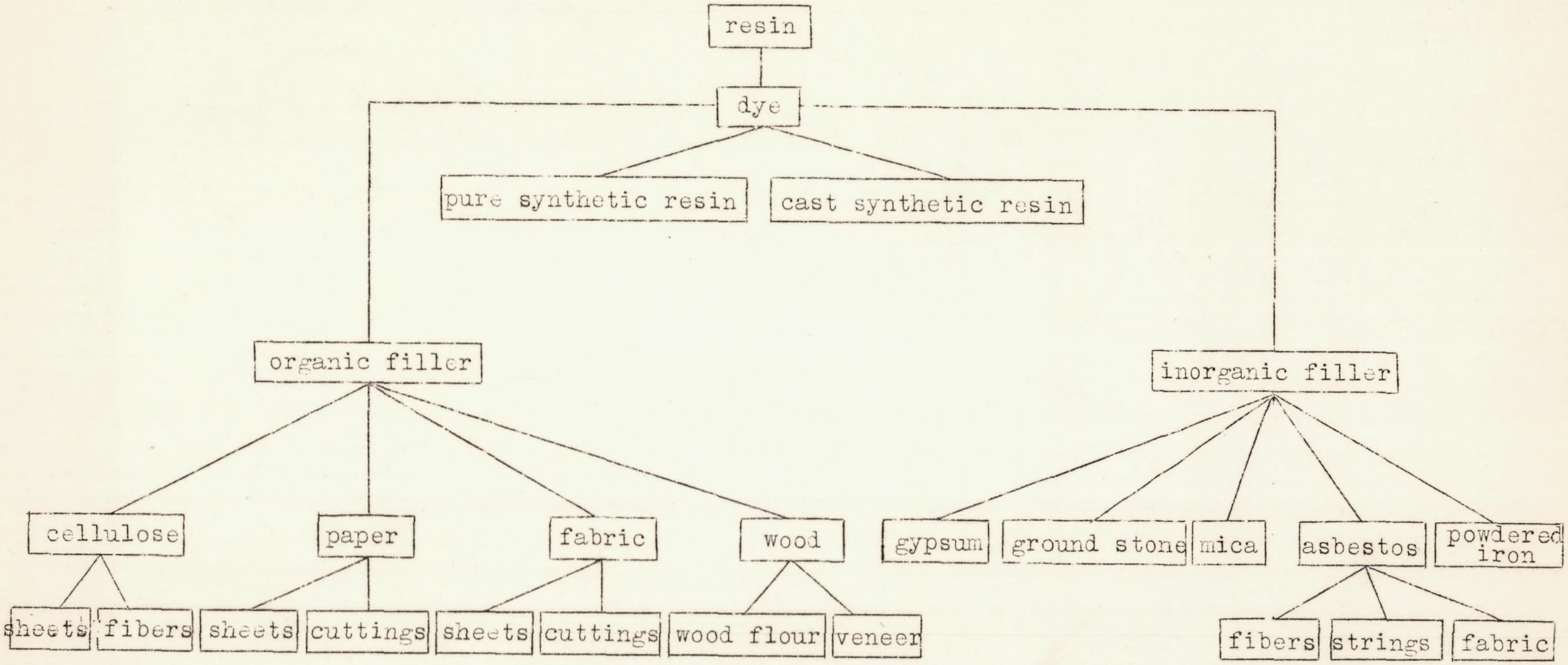


Figure.2.- Binders for the synthetic resins.

Composition	Notation	Weight kg/dm³	Tensile strength σ_B kg/cm² minimum	Compressive strength σ_{-B} kg/cm² minimum	Bending strength $\sigma_{B'}$ kg/cm² minimum	Impact strength a cmkg/cm² minimum	Elasticity modulus E kg/cm² reference value
Phenol plastic a) with organic filler (wood flour)	S	1.4	250	2000	700	6	55000 to 80000
b) with organic textile	T	1.4	250	1500	600	12	70000 to 100000
c) with organic filler	l	1.8	250	1200	500	3.5	90000 to 150000
d) with organic textile	M	1.8	250	1200	700	15	90000 to 160000
Amino plastic with organic filler	K	1.5	250	1800	600	5	50000 to 100000

Figure 3.- Plastics and their fillers used at the present time.

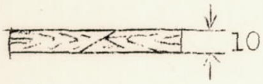
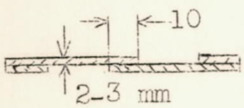
Material	Condition of specimen	Strength limits	kg/cm^2 average
		Bevel joints 1:4	
Synthetic resin paper sheets	dry wet	133 to 163 111 to 159	144 137
Synthetic resin fabric sheets	dry wet	53 to 64 47 to 63	60 55
Synthetic resin veneer plates	dry wet	211 to 243 80 to 120	222 107
		Overlapping joints	
Synthetic resin paper sheets	dry	43 to 62	53
Synthetic resin veneer plates	dry	62 to 67	64

Figure 4.- Strength of glued joints of synthetic resin materials.

	Pure synthetic resin	Wood flour filler type S	Cuttings filler type T	Pine wood
Specific weight kg/dcm^3	1.3	1.4	1.3	0.5
Tensile strength kg/cm^2	200-400	400	500	1000
Compressive strength kg/cm^2	1000	2000	2000	500
Bending strength kg/cm^2	450	950	1200	800
Specific impact work cmkg/cm^2	4-8	8-10	20-30	50-100
Elasticity modulus kg/cm^2	27-35000	40-50000	40-50000	110000
σ_B/γ	1.5-3	2.8	4.0	20
σ_{-B}/γ	7.7	14.3	12.5	10.0
$\sigma_{B'}/\gamma$	3.5	6.8	9.3	14.0

Figure 5.- Strength coefficients of synthetic resin plastics.

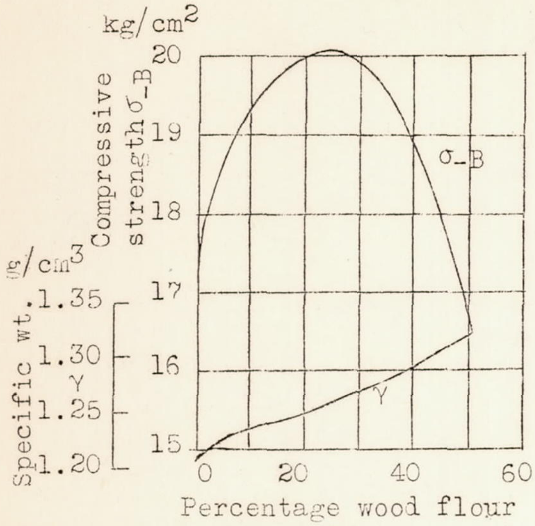


Figure 6.- Compression strength of plastics using wood flour as filler for various percentages of filler.

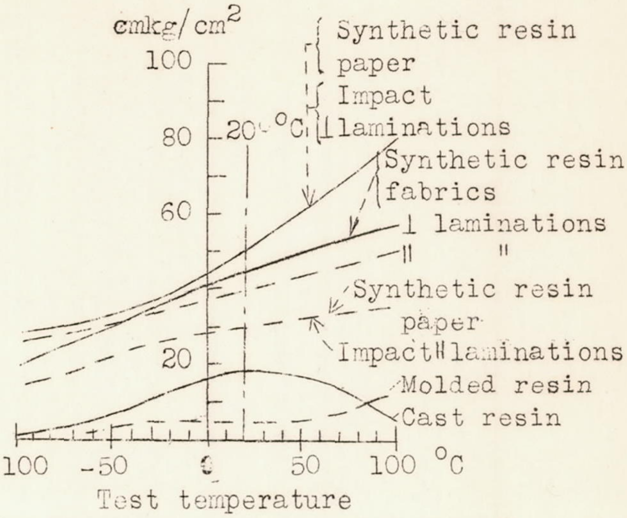


Figure 8.- Impact strength of synthetic resins at various temperatures.

Molding pressure	157 kg/cm²	314 kg/cm²	630 kg/cm²
E modulus in tension	49,000 "	58,000 "	70,000 "
E modulus in bending	53,000 "	62,000 "	77,000 "
Tensile stress	525 "	453 "	423 "
Spec. wt.	1.46 g/cm³	1.46 g/cm³	1.44 g/cm³

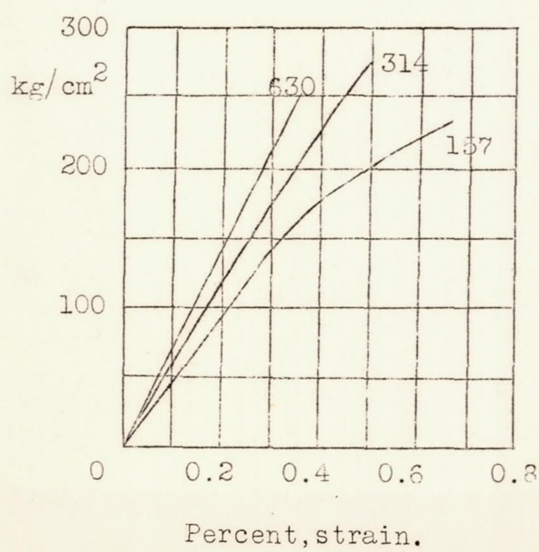


Figure 9.- Strength of synthetic resin fabrics at various high molding pressures.

	Synthetic resin paper	Synthetic resin fabric	Synthetic resin veneers	Spruce	Birch plywood
Specific weight kg/dcm³	1.4	1.35	1.0-1.3	0.5	0.7
Tensile strength kg/cm²	1700	700	2000	1000	900
Compressive strength kg/cm²	1670	1800	1600	500	400
Bending strength kg/cm²	3000	1430	2700	800	800
Specific impact work cmkg/cm²	54	46	90	50-100	20-50
Elasticity modulus kg/cm²	125000	66000	240000	110000	100000
σ_B/γ	12.1	5.2	15	20	11.5
σ_{-B}/γ	12.0	13.3	13	10	5
$\sigma_{B'}/\gamma$	21.4	10.6	22	14	10

Figure 7.- Strength values of laminated synthetic resins.

Fibrous materials	Agave	Agave	Sisal	Aloe
Condition	Threads	Unraveled threads	Stretched fibers	
Tensile strength kg/cm²	1260	2100	3200	2260
Compressive strength kg/cm²	1320	1320	1330	1250
Bending strength kg/cm²	2590	3240	3050	2980
Elasticity modulus kg/cm²	265000	248000	313000	221000
Impact strength cmkg/cm²	--	240	--	533
Specific weight kg/dcm³	1.2	1.30	1.37	1.36
σ_B/γ	10.5	15.4	23.4	16.6
σ_{-B}/γ	11.0	9.9	9.9	9.2
$\sigma_{B'}/\gamma$	21.6	23.8	22.3	21.9

Figure 10.- Synthetic resins with raw fiber fillers.

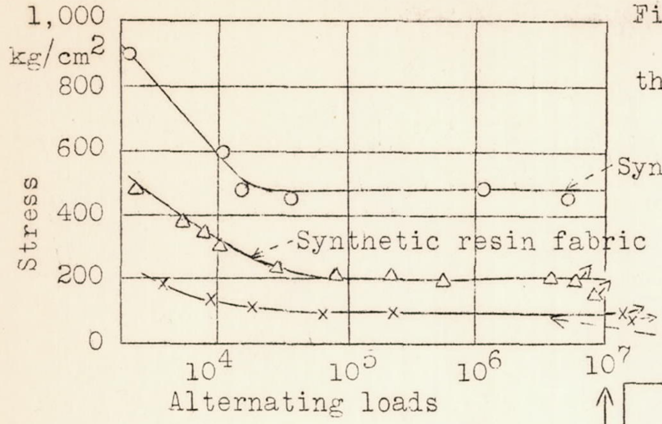


Figure 11.- Circular bending tests with synthetic resins.

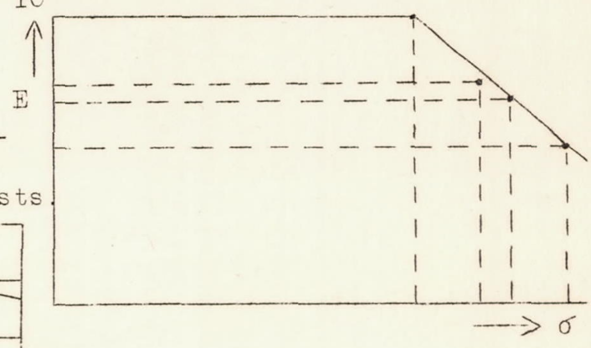


Figure 12.- Determination of endurance strength of synthetic resins through short time tests.

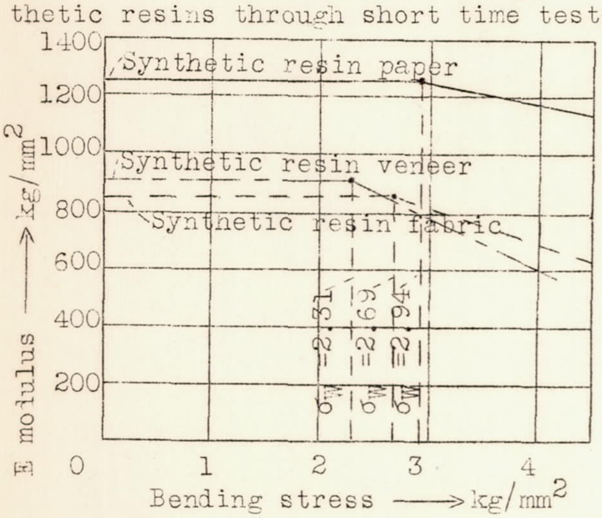


Figure 13.- Endurance bending strength of synthetic resins determined by short time continuous bending tests.

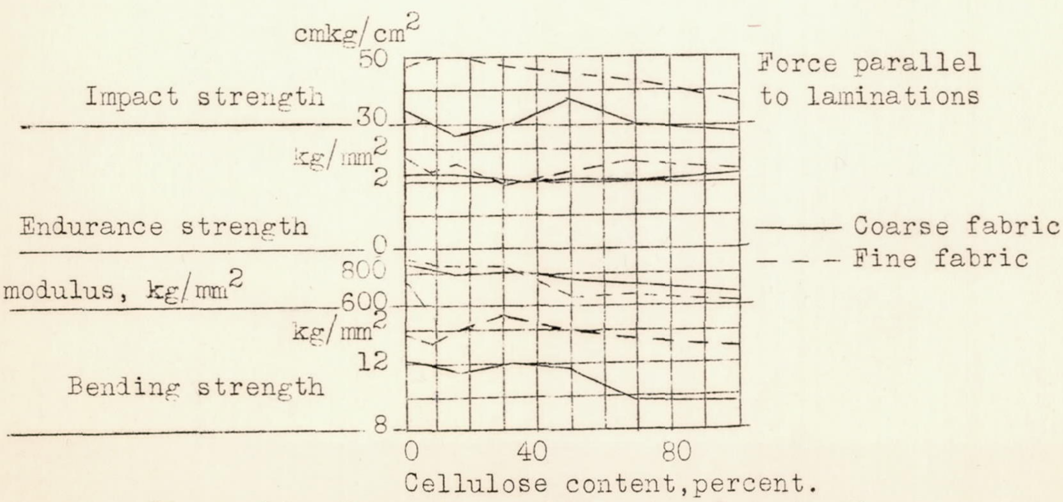


Figure 14.- Strength coefficients of synthetic materials for varying cell wool (zellwolle) content.

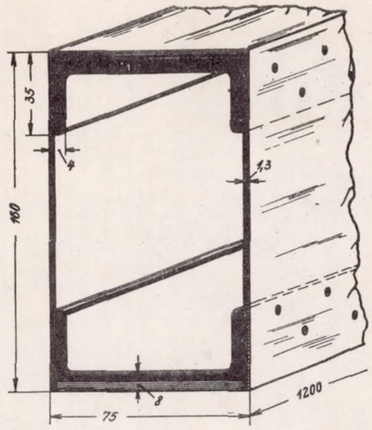


Figure 15.- Dimensions of built up spar of synthetic resin materials.Flange of pressed paper with pressed on veneer layers. Web of 5-ply pressed birch veneers with outer fabric layers. Joining with synthetic resin and wood screws.

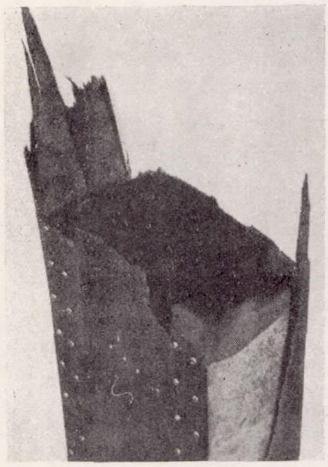


Figure 16.- Showing failure of synthetic resin spar.

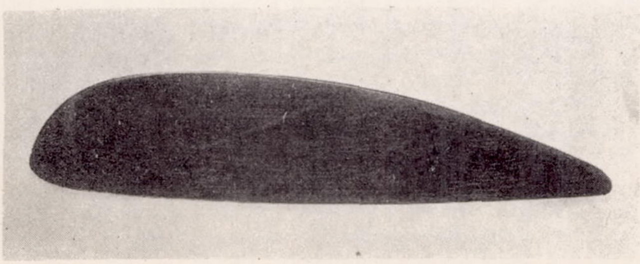


Figure 18.- Section through micarta propeller.

Properties		I Birch-wood	II 50-ply birchwood glued with film (6 transverse layers)	III Birch 50-ply impregnated and compressed (6 transverse layers)	IV Increase in percent as compared with all wood	V 100 parallel laminations of birch veneer
1. Specific weight γ		0.67	1.0	1.21	+81	1.15
2. Tensile strength σ_B kg/mm²	long.	1380	1280	2090	+51	2250
	trans.	75	383	415	+ 455	--
3. Compressive strength σ_{-B}	long.	700	1150	1620	+132	1750
	trans.	90	540	835	+830	
4. Bending strength $\sigma_{B'}$	long.	1400	2200	2880	+103	3540
	trans.	100	550	580	+480	
5. Modulus of elasticity E kg/cm²	long.	160000	215000	258000	+61	311000
	trans.	5800	48000	70000	+1100	
6. Shear modulus G kg/cm²	long.	8000	15000	15400	+92	--
	trans.	--	--	12300	--	--
7. Alternating bending strength σ_W kg/cm²	long.	340	--	760	+124	--
8. Specific impact work cmkg/cm²	long.	130	85	104	-20	--
	trans.	4	15	12	+200	--
9. Percent moisture taken up after 50 hours		43.3	8.0	3.0	-93.5	--
σ_B/γ	long.	20.5	12.8	17.3	-15.3	19.6
	trans.	1.1	3.8	3.35	+ 200	
σ_{-B}/γ	long.	10.5	11.5	13.4	+ 18	15.2
	trans.	1.3	5.5	6.9	+ 430	--
$\sigma_{B'}/\gamma$	long.	21.0	22.0	23.8	+13.4	30.5
	trans.	1.5	5.5	4.8	+ 220	--
[illegible]	long.	2400	2150	2150	-14	2600
	trans.	87	480	580	+570	--
G/γ	long.	120	150	127	+ 5	--
σ_W/γ	long.	5.1	--	6.3	+23.5	--

Figure 17.- Mechanical properties of developed synthetic resin products as compared with wood.

	Lowest value	Highest value	Mean value
Specific weight (g/cm^3)		1.38	
Tensile strength (kg/cm^2) ∥ laminations	472	814	645
Compressive strength (kg/cm^2)			
∥ laminations	1480	1660	1600
⊥ laminations	2620	2730	2670
Beveling strength (kg/cm^2)			
∥ laminations	912	1660	1335
Specific impact work (cmkg/cm^2)			
∥ laminations	11.6	20.0	16.9
⊥ laminations	18.6	21.5	19.7
E modulus (bending)			
∥ laminations	--	--	118000

Figure 19.- Strength coefficients of laminated plastic using paper filler.