
High Temperature Behaviour of Organic Materials for Aircraft

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ABSTRACT

A systematic study of thermogravimetric and thermodifferential analysis of the elastomers (rubbers) used in aircraft has been made. It was possible to identify the thermal weak points, i.e., the temperatures at which each material is more sensitive. It was likewise possible to identify the temperatures of spontaneous ignition for each material. The research work concerning the most common plastic materials and substances normally added to increase some advantageous properties is in progress. The purpose is mainly to select those additives which are able to increase the thermal resistance of the plastic materials without modifying the other obtained properties.

In aircraft, when we speak of non-metallic materials, we refer to a range of different-seeming and differently applied materials, which are all basically organic. This term, as is well known, refers to compounds of carbon: although many of them are prepared and described today, they all possess a common range of characteristics.

The organic materials most frequently in use are: plastics, rubbers, paints, adhesives and textiles. Not infrequently, the same family of compounds can be used to get products for different purposes simply by the displacement of certain atoms in the molecule, or else by the insertion of special functional groups in the same molecule.

Other materials are at present being studied which may, in a certain sense, be considered as something in between organic products in the strict sense of the term, and the other large category of inorganic substances. Already there are good grounds for hoping for success with products which have other elements besides carbon as their basic element and also contain other different elements, such as phosphorous, silicon, boron, aluminium, titanium, etc.

Studies are being orientated especially on the thermal behaviour of materials

— aside from their mechanical characteristics, which are of interest whatever the application and particularly for aircraft.

The essential objects of study are: the maximum of temperature to which a material may be brought without any negative effect on its properties; the degeneration of original properties after a material has been kept at a certain temperature for a given time; and, if the material can resist very high temperature for a limited time, to what extent any modification caused by heat is reversible, *i.e.* the material will return to its original conditions after cooling.

For certain special uses, on the other hand, we study whether a material can undergo surface decomposition as the consequence of high temperature, provided that such decomposition is limited in surface, so that the new structure may help to protect the underlying strata from further decomposition, which might lead to the total destruction of the part. In this case, the special phenomenon of 'ablation' is encountered, which is being studied a great deal today, especially as applied to missiles, and here is also a need to study the kind and quantity of gases that form on the surface, as a consequence of decomposition.

Plastic material, rubbers, paints or adhesives are not made up from a single product: we might say, on the contrary, that they are formed from a basic product of macromolecular structure — by this term we denote that the elementary particles which form it have a much greater mass than that of traditional materials. What is more, not all the particles in a given product are equal, their mass varies from a minimum to a maximum value according a statistical law. The mass of particles, and also their distribution, are already of importance from the point of view of thermal behaviour.

During preparation, various ingredients are added to the basic macromolecular substance which, according to function, are called fillers, plasticizers, stabilisers, anti-oxidants, carbon blacks, etc. The nature and quantity of these additives has an undoubted influence on the thermal behaviour of the finished product.

Finally, the method of preparation has a certain effect on the final properties of the part. It can thus be concluded that many parameters are involved in attributing the behaviour under high temperature.

Very often, in speaking of mixtures, we are led to believe that each component maintains all its properties unchanged, just as when it was considered as a product in itself. If this were the case, each component of a mixture would be inert in relation to the mixture itself. But this is not the case: mixtures are, in fact, prepared and dosed to produce the best possible results for a given use. Even if certain additives are introduced for purely commercial purposes, *i.e.* because the basic product is expensive, the material obtained is always tested, in the end, to find out whether the additions have had any negative effect on the properties.

Certain tests are made on these materials to determine their resistance to high temperature. For plastic materials these tests are as follows:

(a) Vicat penetration, used to determine at what temperature a fixed-sized penetrator enters the mass;

(b) Heat distortion test, to determine at what temperature a sample of the material bends as a result of a predetermined load.

It is no accident that these tests are carried out at a fixed rate of temperature ($2^{\circ}\text{C}/\text{min}$): slower or more rapid heating would, in fact, produce different reactions in the material.

It is prescribed that specimens of certain materials should remain in a thermostatic oven at a given temperature for a given time. Subsequently, when the material has returned to room temperature, certain mechanical tests are carried out, *e.g.* the tensile strength test.

For elastomers (rubbers), additional tests are prescribed such as, for example, compression set: a circular cross-section sample is kept for an adequate time under high pressure at a high temperature. After this, the sample is allowed to cool and its height is measured, and thus its spring-back checked: the greater this is, the more evidence for concluding that the material is a true elastomer. This test is especially important when the material is designed for the manufacture of gaskets.

All these tests, like all other mechanical and physical tests, have the disadvantage of not being made with perfect reproductions of actual working conditions. Although it can, in fact, be affirmed that they are repeatable and, in the majority of cases, also reproducible, thus possessing undeniable advantages when testing is being done, it is also true that they are conventional — *i.e.* in practice, the material will never be subject to stress under just these conditions, but under others. The test conditions can only be approximate to a greater or lesser extent.

Although, at least, the tests just referred to derive from a standard established after discussion by the individual nations, and often also at the international level, the same cannot be said for ablation tests. These have been made at individual laboratories (even in a single country) without any agreement having been reached, according to the methods and conditions that seemed most suitable to the individual research. The result has been that some extremely simple (possibly excessively so) methods and equipments have been devised, as well as others that are highly complicated and expensive. The consequence of this is that the results of such tests cannot be compared in any way.

At a certain temperature, organic materials undergo profound and irreversible changes, *i.e.* they decompose. In macromolecular materials, this decomposition may lead to depolymerisation, with the formation of the original monomer, from which, if required, the polymer can be obtained again. But more often than not the decomposition is irreversible and volatile

substances are formed. The course of this type of phenomenon depends on the temperature rate of the heating process, and also on the length of time the material is heated. It will behave differently if it is immediately brought to a certain temperature and kept at it for a given time.

The latter process is normally applied for testing protective coatings. They are applied to the (metallic or other) surfaces for which they are intended and left to dry at least ten days. After this treatment, the samples are placed in thermostatic ovens at the test-temperature. They are subjected to mechanical tests, the 180° bend test in particular, to find out whether the paint has lost its elastic and adhesive properties: this is determined by whether cracking has taken place.

The cycle-test is another proof of the heat-resistance of protective coatings. The samples are alternately kept for periods at high temperature and cooled in water at room temperature. The same mechanical tests as above are applied at the end of the cycle.

Generally, more or less profound changes begin at lower temperatures than that at which the decomposition begins. Macromolecular materials cannot be said to have a true melting point, *i.e.* a sharp passage from the solid to the liquid state. There are two reasons for this: first because such substances cannot be considered 'solids' in the scientific sense of the term, as their component particles are not arranged in a crystal lattice; second because, as has already been stated, the mass of the various particles reach an energy level at which, by themselves, they would be in the liquid state, the larger particles have not yet reached this level and require more heat to do so. Decomposition phenomena are often observed before the larger particles have liquefied. Thus, the phenomena observed are altogether similar to those produced by attempting to boil — *i.e.* pass from the liquid to the solid state — a fatty- or petroleum-oil.

While it is cooling, the material can generally be moulded into parts which will be different shapes and sizes according to the use for which they are intended. In the course of the finishing process, the so-called 'moulding flashes' can be singled out and later re-used for the other parts. The advantage is that all wastage can thus be eliminated; however, it should never be forgotten that the material is thus exposed to thermal cycles which, if repeated to excess, may produce changes of their own which may be of greater or less importance.

Under certain changes, the material may undergo permanent deformation even at temperatures below that of softening, *i.e.* of moulding. Macromolecular materials are notoriously more prone to the phenomenon known as 'creep' or viscous flow than the traditional ones. We normally try to eliminate this by using what are known as 'reinforcing agents'.

The fillers themselves, both organic and inorganic, already have a fair amount of reinforcing action on tensile strength and other fundamental

mechanical characteristics. But fibrous reinforcing materials are those that do most to eliminate or, at least, diminish, creep. All fibres are subjected to orientation of their component particles, either by a natural process, or (if synthetic) as a result of special stretching during industrial processing. Thus, greater cohesion is attained and consequently, greater mechanical resistance — producing almost total insensibility to creep.

The most important reinforcing agents are the glass fibres, in the form of mat or cloth. In the latter case, the reinforcement is of even more importance because it has very strong mechanical properties. The composition of the glass may vary: it has generally been observed that the higher the silicon dioxide content, the better the final properties of the material.

Adhesion of glass fibres to macromolecular materials is obtained by the application of special products to the surface of the fibres: we can call these 'intermediaries'. The firmer the adhesion, the better the thermal properties, because the plastic shows less tendency to creep at moderately high temperatures, the part is less likely to become deformed. Improvement is observed even when ablation takes place.

Our present studies are thus designed not only to obtain products more and more resistant to heat, but to find additives which, without altering the other properties, give increased thermal resistance.

As we have seen, the solution of this problem is not easy to find, since several factors are involved, namely, as we have already suggested, the basic macromolecular materials on the one hand — with all the variables we have referred to — and on the other the various ingredients, of different qualities and quantities.

The characteristics of all materials depend on their inner nature: especially on the structure of the atoms which compose the molecule; the bonds which allow the formation of the molecule itself; the polarity of the molecules — particularly in surface phenomena, *i.e.* those of contact between bodies of different nature and composition; and, finally, on the 'history of the material' *i.e.* the overall effect of all treatments and processing undergone before the part is finished, ready to be assembled and used in accordance with a fixed design. The final consideration is the one that makes materials dissimilar which, if examined by eye alone, would appear altogether similar, if not identical.

It is therefore necessary, before making practical tests, to make a profound study of the inner nature of the material under examination, making use of all the methods available to science today. The overall result of such investigation is to provide a 'structural' picture of the material, which is of great advantage in discovering the various uses to which it can be put.

The introduction of energy, in its various forms, may modify the material to a greater or lesser extent, as energy itself modifies certain of the bonds between the component particles.

Spectrophotometry at the various wavelengths, ultra-violet, infrared and visible, allows us to investigate what modification may take place in the atoms and molecules as the result of energy stress in the field of radiant energy. It can thus be discovered whether a particle may be more or less sensitive to such radiations, depending on whether or not it is in the vicinity of other equal or different particles. A great deal of laboratory equipment has already been assembled for this purpose, and can lead to very interesting results.

At the Chemical Laboratory of the Italian Air Force, tests on thermal analysis have been carried out, as well as studies aimed to demonstrate the different reactions of the materials to radiant energy, and already the results have been highly satisfactory.

It should be noted that the interpretation given to these tests does not always originate from an exact definition of 'thermal analysis'. In one of the most recent and successful works on this subject, for example, it is stated that the phrase 'thermal analysis methods' refers to those techniques in which certain physical parameters of a system are measured as a function of temperature. In fact, in the same text, chemical changes are also taken into consideration. One chapter is devoted to the phenomena of pyrolysis. While, on the other hand, other phenomena connected with heating, such as polymerisation, thermosetting, oxidation, etc. can make appreciable and lasting modifications to the material.

Our studies are made principally in the field of thermogravimetric and thermodifferential analysis. Thermogravimetric analysis is a technique by which a sample is heated at a fixed rate and the variations in weight are measured in relation to the temperature curve. The variations may be positive (*e.g.* combination with oxygen) or negative (the loss of any of the constituents, or serious changes involving the elimination of volatile products). By differential thermal analysis, on the other hand, we mean a technique for recording the thermal effects associated with chemical or physical changes in relation to temperature or the length of time for which the sample is heated. It can be stated that, in general, endothermic effects are produced by transition, dehydration, reduction and sometimes even by some kinds of decomposition; exothermic effects, on the other hand, are caused by crystallisation, oxidation and other kinds of decomposition than those above.

The rate of heating plays an outstanding part in the behaviour of the material; and the curves obtained are undoubtedly of major importance in deciding when to apply the materials.

The equipment we use is manufactured by the firm Netzsch, Selb, West Germany. It consists of three elements: a thermal balance, which is highly sensitive and therefore mounted on a special anti-vibration table; a thermodifferential unit and a recorder. Temperatures can be measured on a range which extends from 0.1°C/min to 100°C/min. It was observed that too high a temperature rate does not produce good results, given the inertia of the oven

in comparison with the recorder. We have worked at 5°C/min and 20°C/min, both in air and nitrogen. The time/temperature curve and the thermogravimetric or thermodifferential curve are traced on the paper simultaneously by the recorder. For the latter, the arrangement is such that the peaks on the left of the basic line represent the endothermal phenomena, and those on the right the exothermal ones. The height of each individual peak indicates the amount of the phenomenon.

After a series of orientation tests, on both elastomers and plastomers, we went on to a series of systematic investigations on the most important elastomers in their raw state, and more particularly on those that are used as bases for the main elastomeric materials that are, or might be, used in aircraft, namely:

1. Natural rubber;
2. Ethylene-Propylene copolymer, 'Dutral' type;
3. Ethylene-Propylene terpolymer, 'Nordel' type;
4. Ethylene-Propylene terpolymer, 'Royalene' type;
5. Polybutadiene in which the cis-isomer predominates, 'Europrene' type;
6. Various copolymers of butadiene and styrene, with varying percentages of styrene, or obtained by adding mineral oil to the emulsion before coagulation, or else through other processes of catalysis;
7. Butadiene-Acrylonitrile copolymer;
8. Polychlorobutadiene, 'Neoprene' type;
9. Polyethylene sulphochlorinated, 'Hypalon' type;
10. Isobutylene-Butadiene copolymer (butyl-rubber);
11. Hexafluoropropylene-vinylidene fluoride copolymer, 'Viton' type;
12. Urethane elastomer, 'Vulcollan' type;
13. Silicone elastomer.

It should be remembered that natural rubber was taken into consideration because it is still in fairly frequent use, especially when 'cut', *i.e.* suitably blended with other types of elastomers. Further, the butadiene copolymers are the most suitable replacements for natural rubber in its most common uses; chlorine-containing products, such as Neoprene and Hypalon, resist ageing better and are self-extinguishing; the co- and terpolymers of ethylene and propylene are recent arrivals and both are remarkably resistant to oxidation caused by ageing and possess good mechanical properties. The copolymer of butadiene and acrylonitrile is the product most commonly used today for parts which are in direct contact with petroleum derivatives, because minimum swelling is produced by contact with them. The copolymers of isobutylene possess the maximum impermeability to fluids, and thus to gases: they are therefore mainly used in manufacture of inner tubes. Fluorine-containing elastomers have excellent thermal-resistance properties — like similar plastomers of 'Teflon' type, which are much better known and

in more common use — they are generally expensive, but their characteristics are such that they are preferred to the other products, especially for missiles. The silicones have good thermal properties, but their mechanical characteristics are rather poor. The series of researches was completed with an investigation into a urethane polycondensate, not so much because it enters fully into aircraft use, as because some of its properties are interesting.

In the course of thermogravimetric analysis it was observed that the diagram of temperature against time shows a slight inner deflection at a certain point, which is different for each sample: this shows an excess of heat with respect to that supplied by the apparatus. It is held that we may conclude that this means that the sample ignites spontaneously at that temperature. We were able to observe that this spontaneous ignition does not take place when the test is made at a low temperature rate, *i.e.* 1°C/min; while it is much more marked when the temperature rate is higher. This may well be because of the greater concentration of inflammable products in the case of more rapid heating. On the other hand, when the temperature rate is low, the inflammable products have time to diffuse and become diluted in the environment.

It seems that these observations are important in the case of special uses for rubber products and particularly, for aircraft.

It has been established that each product examined has a thermogravimetric curve of its own, and this is also important from the point of view of analytical identification of every product. Thermodifferential analysis also gives characteristic curves, depending on whether you are working in air or in inert gas (nitrogen), and also on the temperature rate of the test. When we work with inert gas, the following is the most interesting phenomenon to observe: peaks are seen which reveal endothermic phenomena at (or slightly below) the temperature at which exothermic effects, and, probably oxidation, were observed on the diagrams that were obtained as the result of heating in air. It would appear that these materials are subject to decomposition before oxidation takes place, and are thus left in the optimum state for subsequent oxidation. The decomposition is revealed by the endothermic peak, which is masked by the exothermic one when the analysis is made in air.

In the course of this part of our investigation, 61 graphs were drawn. They enabled us to establish the 'weak points' of every kind of elastomer examined, *i.e.* the temperatures at which important changes appeared in the materials under pre-established heating conditions.

Similar investigations will be made on the most important plastomers. Many of them are used in aircraft, namely:

1. Ethylene and Propylene polymers, with special regard to those obtained from stereo-regular catalysts, and which thus possess considerable mechanical and thermal resistance;

2. Chlorine and fluorine derivatives of the above: especially chloro- and fluoro-vinyl polymers and vinylidene compounds;
3. Styrene polymers and copolymers;
4. Methacrylate polymers, paying special attention to those that have undergone mechanical treatments to make them more resistant, such as stretching, or those which have had their characteristics improved by copolymerisation;
5. Acetal polymers, used today when great wear-resistance is required;
6. Simple and modified phenoplasts;
7. Polyesters with particular reference to those reinforced with glass fibres and cloth;
8. Epoxy-resins, as above;
9. Allyl resins, as above; but also with special reference to tricyanurates, described as being more resistant to heat;
10. Fully or partially fluorinated resins;
11. Silicone elastomers;
12. Polyamides;
13. Polybenzimidazoles.

We have already stated that several parameters influence these materials, namely: the average molecular weight, the distribution of molecular weight according to a statistical law, the shape of the macromolecule. But, it should be remembered that, when speaking of a family of elastomers, it may consist of a very large number of members, each only slightly different from the others.

For the moment we shall try to limit the investigation to those members which have been successfully applied in aircraft.

Progress of research in the field of elastomers, which has been highly satisfactory so far, leads us to believe that the thermal behaviour of the products already used may lead to interesting suggestions regarding possible modifications with the aim of improving their characteristics.

A material which behaves in a prevalently elastic or plastic manner is not composed exclusively of a macromolecular product. Other substances are added, in different qualities and quantities, according to the use for which it is intended, but also, very often for economical reasons.

We have already spoken of fillers and especially those used as reinforcing agents, to improve mechanical characteristics. But even in this restricted range of properties, not all types of filler achieve the same result, *e.g.* while certain products help to increase the tensile strength, others increase impact resistance. Further, certain fillers are used more for their thermal resistance (*e.g.* asbestos) or to improve the electrical properties, than for mechanical resistance.

In the rubber field, the problem of fillers is anything but simple. The fillers generally preferred are the carbon blacks, but even among these there is a wide

range of choice, according to the methods used in their manufacture and the properties they can provide to the finished product. Further, it must be said that certain elastomers must not be filled with blacks, and this is the case with silicones, which must be filled with colloidal silica.

Another class of additive is plasticisers, *i.e.* generally micromolecular compounds designed to increase the plasticity and flexibility of products. Several hundred plasticisers are already known, and each is added to obtain the characteristics required for the specific use intended. In other words, account must be taken of the environment in which the part is to be kept, as plasticisers are very sensitive to environment, both physical (high and low temperatures) and chemical (special radiations, oxygen, liquids, etc.).

Chlorinated plastic materials are subject to ready changes by the action of light and heat. For this reason, special additives are available, known as stabilisers. These may be very different in nature, *e.g.* organometallic compounds, or fatty acid salts for heavy metals.

For purposes of identification, or sometimes merely for aesthetic purposes, the so-called pigments are added to these materials, *i.e.* powders of compounds which will give a predetermined colour. The fact that pigments absorb radiations selectively, means that only the non-absorbed radiations are available, and this reflects on their resistance to the radiations themselves.

Whatever the nature or quantity of an additive given to a plastic or a rubber, it is certain that the interaction between matter and energy will be affected. It is therefore necessary for the whole series of thermoanalytical tests to be repeated on the finished products, in the same way as they were made on the basic ones. During the research phase, it is essential to have a good knowledge of the centesimal composition of the finished products and the exact nature of the ingredients added. Whenever possible, a large stock of samples should be kept, so that it is possible to take into consideration which variations — improvements or deteriorations — can be imputed to every type of additive.

Such an investigation is certainly long, but will surely enable us to reach an optimum formulation of blends from plastomers and elastomers most suitable for each use. On this point we feel that there is a consideration to be made. These materials are all-too-frequently placed on the market with the slogan 'a material for each use'. Given the ductility and variability these products may possess, there is some truth in this; but it is a frivolous claim unless the use is clearly known and a thorough study has been made in each case. It is highly unlikely that the firms manufacturing these materials make a thorough study of their characteristics that would determine the requirements for every application.

The third part of these researches must turn on practical tests. Once the 'weak points' of each basic product have been established by thermal analysis,

and once the best formulations of ingredients are determined to reach an optimum quality, a kind of check test must be made.

We shall prepare laminates of elastomers or plastomers, made as uniformly as possible, according to the best formulations achieved by study and the criteria already outlined. These laminates will provide at least five samples for each type of test. The tests (mechanical, thermal and possibly optical and electrical) will be carried out according to the ASTM methods. These are still considered to be the most effective, and this recognition is international, therefore the results obtained will enable us to speak in a universally-understood language.

Once we have obtained a complete panorama of the physical and environmental conditions of the material, together with perfect knowledge of the chemical composition of the ingredients, samples, prepared in an altogether analogous manner, will be kept at fixed temperatures for a given time. The test-temperatures will be selected to correspond with those indicated by the thermal analysis as the 'weak points', *i.e.* as we have already seen, the temperatures at which fairly important phenomena occur to the materials.

The samples, treated as above, will then be given physical and environmental tests. The aim is to determine the percentage degeneration of each characteristic: sometimes the degeneration will be obvious to simple sight but, in the majority of cases, it will be necessary to prepare numerical data to eliminate as far as possible the subjectivity of the analyst.

Here, too, the investigation appears rather laborious. In fact, in addition to the composition of materials, test-temperatures and the time for which each sample is left at a given temperature, the external surface of the sample and its thickness will be important. As we are dealing with materials that are very poor heat conductors, it is evident that the changes will be the more marked the larger the exposed surface of the samples, and the thinner it is. In the case of elastomers, it is probable that more evident changes will appear in samples used to test the tensile strength than in those used to test compression set.

But, even in these cases, chemical analysis may help. It is very probable, in fact, that, as the result of heating, the relatively-volatile plasticisers and other ingredients will be lost. In this connection we must say that the Chemical Laboratory of the Italian Air Force has also carried out research (as reported in various publications) on the products obtained after pyrolysis in inert gas (nitrogen or helium), both for rubbers and plastics. We maintain that it will be of considerable interest to repeat the pyrolysis of the materials that have undergone decomposition. It is probable that the products obtained will be perceptibly different from those obtained from the original products. Examination of these pyrolysis products has been successfully carried out by means of gas-chromatography, *i.e.* by selective adsorption in tubes filled with support materials of a special polarity, and subsequent gradual elimination

of the individual components thus separated and shown up by a special system of highly-sensitive detectors.

We shall not claim, after these tests, that we are in a position to say any last word on the susceptibility of plastic materials to the phenomenon of ablation, as referred to at the beginning of this report. But it is maintained that the whole series of tests will provide new elements for the understanding of this interesting phenomenon.

Interest in ablation is not confined to the formation of the protective surface coating which appears on these materials under violent thermal shock. It is also of interest to discover the nature and quantity of the gaseous products that are formed as the result of decomposition, and which influence the boundary layer, especially in the study of missiles. It will be essential to collect these products and subject them to chemical analysis in order to complete the investigations.

In concluding this report, it must be added that thermo-analytical tests are being carried out on materials (elastomers only, so far) subjected to various radiations.

It is our opinion that researches of the kind described have an important double scope. First, that of casting the maximum light on the inner nature of the matter, working on the presupposition that the more we know about matter itself, the better can it be exploited for man's various needs. Second, the aim of finding, within the family of non-metallic materials used in aircraft, those materials which agree better than others with the delicate requirements we are called on to study.

I trust that I have made it clear that this kind of research is anything but simple. This is because different factors affect the results. First and foremost comes the nature of the materials which, because they are organic, are subject to an almost infinite number of apparently invisible changes. Then, there is the fact that organic materials are sensitive to different agents, and this means that a material studied theoretically may have unpleasant surprises in store if it is hot-moulded too hastily. Next, we have to reckon with the various ingredients which have both qualitative and quantitative effects on the final properties of the material. Finally, as we have seen, and as I take the liberty of repeating, there is the difficulty of the interpretation of the results, starting in the simple case of practical tests, with samples of different shapes and dimensions, according to the tests to be carried out, and which, in any case, are all of considerable importance.

I must remind you that, at the present moment, efforts are being made in various research centres to prepare materials which, although they are basic macromolecular compounds, also contain, wholly or partially, elements different from carbon. It is not many years since such studies were first begun, and we can already glimpse the possibility of some success. From the

practical point of view, it is still too early to draw any conclusions, but it appears that, when the time comes, they will be of interest from the thermal viewpoint.

I believe that the series of tests that has been initiated at the Chemical Laboratory of the Italian Air Force may serve as the basis for future research on different materials. I have brought with me some of the most significant diagrams that we have so far obtained, and I will be glad to make them available to anyone who is interested. I should be delighted if others were to decide to carry out similar tests, as this would be a contribution to uniting our efforts in research on these materials. They are being used more and more, but there remains the reservation on their thermal weakness, which we must succeed in removing progressively.