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EROSION RESISTANT COATINGS

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16. Abstract Apparatus for measuring the resistance of materials to erosion is examined, and a scheme for standardization of the test parameters is described. Current materials being used for protecting aircraft parts from erosion are surveyed, their chief characteristics being given. The superior properties of urethane coatings are pointed out. The complete cycle for painting areas subject to erosion is described.					
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The destructive effect or erosion caused by the high velocity impact of solid or liquid particles on material in rapid movement was examined for the first time by Honegger in a work which appeared in the Brown Boveri Rev. [1].

The starting point was provided by a study, performed by the same Honegger, of the damage caused to metallic parts of steam turbines by repeated collisions with drops of water at a velocity of approximately 200 m/sec.

Although the phenomenon was of considerable importance, few authors had developed the subject any further by 1943 [2]. Only in 1945, as a consequence of damage caused to the coating film on the antennae of the B-29 bomber, did new interest arise in this field of research, which has recently been revived by the adoption of modern jet aircraft capable of velocities much higher than sound [3, 4, 5, 6].

Recently, for example, damage caused to the infrared apparatus shields of the F-104 fighter was attributed to the effect of drops of rain.

For all of these reasons systematic studies regarding the erosion of materials in high velocity movement, caused by solid or liquid particles, have been begun in various parts of the world in technologically advanced countries.

In general the solid bodies are composed of sand (the erosion can be verified when more than one airplane lands or takes off simultaneously, or when airplanes fly at a low level over deserts or sandy areas), or icy hail.

The liquid bodies are drops of rain which collide against flying aircraft at high velocity.

* Numbers in the margin indicate foreign pagination.

A preliminary condition for conducting systematic studies was the availability of apparatus able to be used for the various erosion resistance tests for the various materials without the test conditions having to be changed each time.

Apparatus Developed

The apparatus to determine resistance to erosion, developed for systematic studies to be conducted under reproducible conditions, are substantially of three types:

1. A mobile sled with a screen made of the material being examined, impelled by rockets and moving on tracks, colliding with artificial rain or subjected to erosion on the part of non-rigid screens made of various kinds of material. This system is particularly used in the United States.
2. An arm rotating at high velocity on a horizontal or vertical plane, carrying at its ends specimens of the material under examination colliding with drops of water or solid particles; this apparatus has particularly /337 been developed in Germany and England.
3. A wind tunnel in which a specimen of the material under examination collides with wind or drops of water or solid particles. This system has been especially tested in France.

A general study of the phenomena cannot be carried out with all three types of apparatus, which also differ considerably in the cost of installation and execution.

The apparatus which has the sled as its principal part, in addition to cost, does not allow the temperature of the agent causing the erosion of the specimen of material under examination to be fixed, and in general none of the variables can be fixed in a very rigorous way; even system 3, i.e.,

the wind tunnel, is not without inconvenience, and therefore in this paper we present only the results obtained with system number 2 (rotating arm), which is also the test apparatus expected to be produced in Italy.

Rotating Arm Apparatus

The principal part of the apparatus, shown in Figure 1, is a rotating arm put into motion by a suitably arranged and connected motor. The apparatus realized by Dornier [7], 120 cm in diameter, permits a maximum velocity of the arm of 475 m/sec.; at this velocity the specimen of the material under examination placed at the ends of the arms is subjected to a centrifugal acceleration of 19,000 g. In order to produce the artificial rain or some other erosive agent, jets or other systems which make it possible to obtain single drops of water or exact quantities of erosive agents are arranged at regular intervals in the trajectory of the specimen under examination.

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The experimentation can be followed from an isolated cabin by means of telescopes, stroboscopic illumination, or can be photographed with highspeed movie technology.

Standardization of Test Parameters

The erosion of a material caused by solid or liquid particles depends on a large number of factors which must be determined in order to compare the behavior of different materials.

It is particularly necessary to define the following test conditions:

- velocity of the rotating arm and the angle of impact;
- density of the eroding agent with respect to air; superficial characteristics of the eroding agent;
- temperature of the specimen and of the eroding agent.

System for producing drops
of water with 8 distributors : Rotating arm

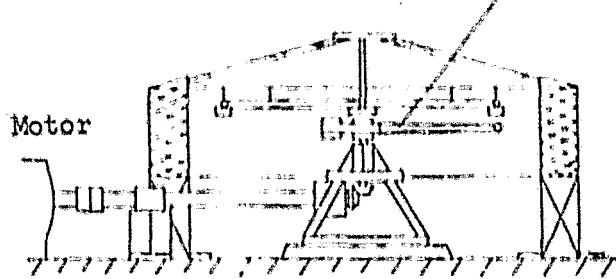


Figure 1. Diagram of the rotating arm apparatus

Quite widespread test conditions are those reported here, considering the eroding medium to be drops of water:

- | | |
|---------------------------------------|--------------------------|
| - impact velocity | $v = 410$ m/sec. |
| - concentration of water in the air | $w = 1 \cdot 10^{-5}$ |
| - mean diameter of the drops of water | $D = 1-2$ mm |
| - angle of incidence of the drops | $\theta = 0^\circ$ |
| - specimen temperature | $T_c = 40^\circ\text{C}$ |
| - water temperature | $T_a = 25^\circ\text{C}$ |
| - gas containing the water | nitrogen to saturation. |

Under these conditions the simplest way of making quantitative determinations consists of measuring the loss in weight, ΔG , of the specimen, resulting in a mean erosion depth of

$$e_{bl} = \frac{\Delta G}{\gamma \cdot F}$$

where γ is the specific weight of the material and F is the area of the specimen subject to erosion.

Figure 2 shows a typical erosion curve.

The impact velocity between the specimen being examined and the drop of water, i.e., the eroding agent, is the parameter to which the greatest variations in erosion depth and intensity are related.

Actually the energy flow across the specimen exposed to the abrasion of the rain increases as a function of the cube of the velocity, while the kinetic energy increases by the square of the velocity, and the number of impacts increases directly with the velocity itself. /339

However, practical experiments performed by the above-mentioned authors at Dornier has shown that in reality the erosion by rain increases, within the velocity range from 200 to 470 m/sec., from the 5th to the 13th power of the velocity, depending on the material.

It has also been deduced from the studies referred to above that the loss in weight ΔG of a material diminishes as the energy needed to break it increases; that is to say that the greater the binding forces which keep the individual crystals or the single molecules of the material together, the greater is the resistance of this material to erosion.

It is not the intention of this paper to examine individually the dependence of erosion on the individual factors which determine it or which have been determined in the apparatus developed. However, what has gone before serves to provide an idea of the complexity and significance of this phenomenon, destined to increase with the increase in velocity at which future aircraft will be able to operate.

Coatings Resistant to Erosion

The scope of this paper is to present coatings resistant to erosion, i.e., materials which can be used to protect and paint those parts of aircraft which

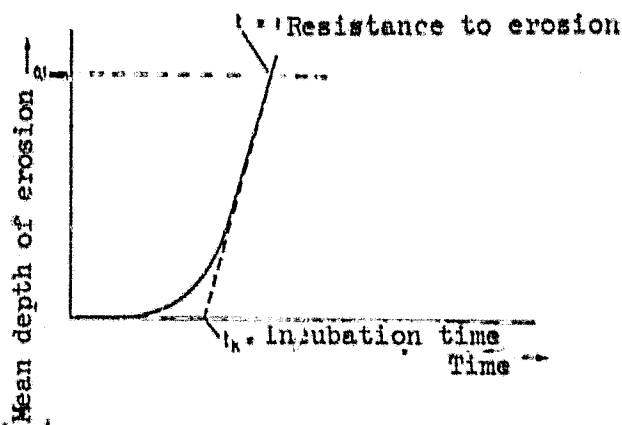


Figure 2. Erosion curve

are subject to erosion at even the velocity at which aircraft in service today can operate, between Mach 1 and 2.

These parts are essentially made up of:

- the front part of the fuselage, the radome and the nose of aircraft;
- the edges of the air intake of the turbines;
- the leading edges of the semi-wings;
- the leading edges of the stabilizer;
- the leading edges of the keel;
- the front caps of the tanks at the wingtips; and
- helicopter rotors.

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All of these parts can be made of light alloy, steel or plastic material reinforced with fiberglass, boron, etc.

Since it is impossible to think of using various paint materials for the different supports, the entire cycle of protective painting must be achieved in such a way as to be able to be applied without inconvenience to the surfaces mentioned above, and should be able to provide positive behavior to every support.

In reality it is necessary to consider at least a triple arrangement of the problems:

- a) compatibility between the various components in the protective cycle;
- b) compatibility between the foundation coating of the cycle and the basic materials of the support; and
- c) adherence between the various components of the protective cycle with each other and the basic materials of the support.

The latter problem is extremely important since there have been observations of flaking phenomena between the components of the painting cycle with coatings not suitably adjusted. In addition there should be an investigation of the maximum adherence between the basic surface of the support, which in every case should be prepared under the best conditions, either by using suitable abrasive means or by employing aggressive substances (e.g., wash-primers), and the undercoat or primer of the protective painting cycle.

Materials Used in Protection

All of these problems were resolved in the 1960's, i.e., with the aircraft of the F-80 series, with the use of an elastomer coating corresponding to the regulations of the specific MIL-C.7439, which was particularly researched to protect the parts made of plastic materials, i.e., the most vulnerable parts of aircraft, missiles, helicopter rotors, etc.

The painting cycle consisted of an undercoating with a base product, mixed in accord with the usage with the catalyst or possibly, if necessary, with the thinner, to be applied in variable thicknesses from 15 to 25 microns. The true and proper coating, resistant to erosion by fine rain, was applied over this undercoating film to a total thickness of 30-40 microns.

This system has not caused any serious difficulties up to even peak velocities close to the velocity of sound with the eroding conditions not being particularly intense.

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But now, with somewhat faster aircraft, with more aerodynamic profiles or intended to operate in African or Asian countries where a significant increase in sand erosion can be found, or in particular seasons of the year with an increase in rain erosion, the above-mentioned system has revealed its limits. At the end of the 1960's and at the beginning of this decade [1970's], it has been replaced with a self-adhesive band which, applied not to activate an adhesive subject placed on the back or applied by pressure, has at least momentarily solved the problem of adhesion which previously failed. However, the proposed system still leaves something to be desired from the point of view of complexity of application and reduced efficiency in real and effective protection against erosion.

Actually the band offered very little resistance to the shock of solid or liquid particles, because it was not hard enough, but it has nevertheless been used for aircraft capable of maximum velocities somewhat above that of sound. However, in the meantime, paintings have been produced and distributed which harden and dry by chemical reaction between the basic component and the catalyst.

With these coatings it is possible to obtain extremely hard and resistant dry films, since the bonds between the various molecules of the substance forming the basic film are of a chemical nature, and furthermore the final molecules obtained constitute an intertwining which cannot be broken by the action of solvents, heat or aggressive chemical agents, but they can pass through the phase of vitreous transition to an extremely hard and fragile state which can lead to rupture of the material.

The two large groups of coating which dominate the field of catalyst coatings are epoxy and urethane, and both have been tested by aviation companies in the United States as antierosion coatings.

The epoxy coatings, which have been particularly researched and experimented with by the Lockheed Georgia Company, have been rejected since it has been found that they have poor qualities for inhibiting erosion because of their low vitreous transition temperature and their tendency to crumble, i.e., the pigments or body come to the exposed surface.

On the other hand the urethane coatings have demonstrated good behavior, better than any found with other materials used previously to protect against rain erosion, a behavior which has also been verified by its use in products manufactured of synthetic urethane resins for stamping.

These coatings have been prescribed in U.S.A. MIL-C.83231, which anticipates two types of coating:

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- resistant to rain erosion; and
- resistant to rain erosion and antistatic, i.e., capable of dissipating the static electricity which causes radio and radar disturbances.

The best urethane coatings resistant to erosion are those which are made up of a component "A", containing a "free oil" aliphatic isocyanate and special antierosion additives, and of a component "B", containing a very branched polyester resin with numerous free hydroxyl groups.

This urethane finish coating should be applied according to the regulation of the above-cited Code, or according to the directions of the Italian aeronautics industry (with the full agreement of the Laboratory Administration of the Military Air Force), in a cycle with the following products or coatings.

1. Pretreatment:

- wash-primer AA-M-P.027 for new structures made of light alloy;
- careful degreasing to eliminate additives which make it easy to form fragments and subsequent leafing on the surfaces made of plastic material; and
- careful preparation for steel surfaces.

All of these treatments have the purpose of making the surface slightly rough where it must be protected, and thus to facilitate adherence between successive layers of the coating.

2. Treatment with primer coatings:

All of the surfaces to be protected should be treated with a primer of standard AA-M-P.023 made up of a base coating with an epoxy film-forming substance of an aromatic nature with a high epoxy equivalent and with anti-corrosive pigments based on titanium dioxide and strontium chromate, plus a catalyst containing a polyamide or polyamine resin dissolved in suitable solvents.

3. Treatment with finishing coatings:

The urethane coating corresponding to MIL-C.83231 is applied to the primer film which is not yet completely dry.

The primer film should not be completely dried to hardness in order to facilitate adherence with the urethane finishing coating, which thus finds a way of establishing some secondary chemical bonds with the substances of an amine or amide nature still present in the primer film.

Note that the apparatus prescribed in MIL-C.83231 to measure resistance to rain erosion is the rotating arm type which has been used as the basis for the comments treated in this paper.

The epoxy primer is applied in thicknesses of approximately 20-30 microns, while the urethane finishing coatings require much larger thicknesses, variable as a function of the particular profile of the piece and the part of the aircraft subjected to erosion. Thicknesses of 100 microns can even be reached in the urethane finishing coating alone for the most exposed zones.

Final Considerations on Coatings

Urethane coatings thus represent the most efficient material produced up to now to resist rain erosion but, in order to obtain the best erosion-resistant properties, adherence to the primer coating, chromatic and chemical stability, and finally the best characteristics of adherence of the primer to the various supports, the most efficient anticorrosive properties, etc., it is necessary to verify both the technological properties of the coatings which should be used and the composition of the coatings themselves, on which a large part of the chemical behavior of the dry film depends.

This is the reason that the Laboratory Administration of the Military Air Force conducts all tests and controls on these materials by subjecting the three fundamental groups of substances forming a coating to separate preliminary and successive analyses [8]:

- volatile parts;
- pigments and body; and
- dry vehicle.

In particular separation by means of high pressure liquid-liquid chromatography of the components of the dry vehicle and successive analysis of the substances, separated by means of spectrophotometric techniques in the ultraviolet and infrared ranges, have provided results worthy of note which integrate perfectly with results from chemico-physical and technological

determinations. In this way a comprehensive evaluation of the materials in question has been achieved, so as to assure fully the practical behavior in the use of the various coatings mentioned above.

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