APPLICATION OF ALLOY STEELS TO AIRCRAFT INDUSTRY

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INCREASED industrial production cannot by itself make a nation prosperous unless proper economic measures are resorted to in the use of such products. This is particularly true in the case of a vital product like steel. It is indeed most appropriate that this symposium on 'Production, Properties and Applications of Alloy and Special Steels' should be held at a time when the country is on the threshold of rapid industrialization under the Second Five Year Plan with heavy targets in steel output. The subject of the symposium has a vast scope. I shall, however, confine my discussion to the application of alloy steels to aircraft industry. An insight into the steel requirements of the aircraft industry will assist in the formulation of definite standards for such of those varieties which can be made within the ambit of raw materials available in this country.

Aircraft industry in this country was first established in 1941 when Hindusthan Aircraft Ltd. took up production of certain types of military aircraft. Though almost fifteen years have passed, the growth of the industry is not as rapid as we could have desired. There is no need to go into the factors which have influenced this slow progress because such a discussion would not be relevant to the subject. However, looking ahead I certainly see a bright future for the industry. Export of trainer aircraft to other countries is in the stage of negotiation and with the resources and trained men now available there is every possibility of building up a stable industry in course of time.

Probably one of the most important factors which influence the success or failure of any industry is the availability of suitable raw materials, and the aircraft industry is no exception to this. It is not uncommon that in the present stage of development an aircraft has to be grounded for weeks or even months for lack of a certain forged or cast fitting which has to be flown from England or America. One may argue that the limited demand does not warrant production of special materials in this country. But it is well to realize that the growth of the aircraft industry is not to be based merely on economic grounds, but should be planned on the wider aspects of national security and emergency requirements as in flood relief work, pest control, etc. One can see that it is necessary for a progressive nation like ours to be self-contained as far as possible. We should be able to supply most of our requirements of raw materials for the aircraft we propose to build.

It is generally true that aluminium alloy forms about 70 per cent of the metal by weight in a modern aircraft and steel hardly a few per cent. In the case of small aircraft having steel-tubular fuselages, the steel content may be a little higher. But this small percentage of steel is very essential and cannot be substituted for. One can eliminate the aluminium alloy wing and substitute it with wood and fabric. But who would think of using wooden bolts and nuts and plastic break-drums. Aircraft industry is a small but an important consumer of quality steel which has to meet very stringent specifications.

I may point out here that demand for high quality has provided the stimulus for the production of better and better materials in the past. Aircraft industry has played a significant part not only in the matter of material development but even in general design methods. For instance, in the early days of aircraft development the orthodox civil engineering design methods were followed. But when man was caught in the grip of an expanding ambition to fly faster, farther and higher in larger and larger airplanes, it became necessary to devise more rigorous methods in design of structures and components. Soon the civil engineers saw the advantages in these new methods and what we now see is a reversal of the process that elements such as thin-walled sections, stiffened panels, lipangles and channels which were once exclusive to aircraft industry are freely employed in structural steel designs at least in foreign countries. In the same manner, quality alloy steels which are specifically needed for certain aircraft or engine parts will eventually find use in many other industries as well.

The stringent specifications that I referred to earlier arise out of the necessity for weight reduction in aircraft. The desire to attain very high speeds coupled with the considerations of economy makes it imperative that the weight should be cut down to the barest minimum. Saving is to be effected not in hundreds or even tens of pounds but ounce by ounce. Taking mere bolts and nuts, for example, a small aircraft may use about two thousand of them, not counting the very large number of screws. Now, if the quality of the material may be improved such that the next lower size can be used without impairing the safety of the aircraft, assuming, of course, that bearing and other criteria are satisfied, then a considerable saving in weight in the order of several pounds may be achieved. For a civil structural engineer who always deals with tons of steel a few pounds either way may mean nothing. But on the other hand it has been estimated by an economist that for an airline company using about 50 airplanes of the same type, a pound saved in the structural weight of the aircraft would mean a saving of several lakhs of rupees per annum due to reduced maintenance cost and increased payload. It is thus important to choose or develop particularly suitable materials for each component in aircraft. Indeed, one might feel that some steel alloys like SAEX 4130 were developed mainly for aircraft use.

I shall now briefly describe some typical applications of steel to the aircraft industry, the type of steels employed for various parts and the kind of loads that act on such parts (Table 1).

One of the important components for which chrome-molybdenum steel tubing is invariably used is the engine mount. The engine mount has to withstand a large number of forces and moments. The thrust and torque along with the airforces on the cowling are all resisted by the mount in addition to the gyroscopic couples due to rotation of the propeller and the vibration forces caused by an unbalance in certain engine parts. Naturally, a component of such importance has to be designed with great care and precision. C.M. steel SAEX 4130 tubing is employed for this purpose. Any improvement on the material has to be considered in the light of the fact that all joints in the mount are to be welded and it should be possible to weld the structure and heat-treat it to the desired strength.

The tubular steel frame for fuselages is also another major steel structure in certain aircraft. The frame has to withstand bending and torsional moments. For small aircraft it has often been found that a tubular steel frame with a fabric covering weighs no more than any other type of design like aluminium alloy or wood and fabric combination. At the same time the construction is time-saving since all joints are made by welding in a jig. Chrome-molybdenum heat-treated tubing is employed for tubular steel framing. Another airframe component for which alloy steel is essential is the landing gear oleoleg. The heavy landing loads are to be resisted in the form of hoop tension in the cylindrical leg. The oleo is often made by shrinking one tube on to another, thus

TABLE 1 — STEELS USED FOR SOME OF THE IMPORTANT AIRCRAFT COMPONENTS

NAME OF THE AIRCRAFT COMPONENT	COMPOSITION, PER CENT								MAX. STRESS, tons/sq. in.
	Carbon	Silicon	Manganese	Nickel	Chromium	Molybdenum	Vanadium	Tungsten	
Nuts, bolts and lightly stressed machined parts (general)	0·15-0·40	0·30 max.	0·50-0·90	—	—	—	—	—	35-45
Plates lightly stressed	0·20-0·25	0·30 max.	0·60 max.	0·30 max.	—	—	—	—	28 min.
Stressed plates	0·25 max.	0·30 max.	0·60 max.	4·50-5·00	0·20 max.	—	—	—	48 min.
Cylinder barrels and air-frame fittings	0·35-0·45	0·30 max.	1·20 max.	1·0 max.	—	—	—	—	33-45
Airscrew shafts and hubs	0·25-0·35	0·30 max.	0·45-0·70	2·75-3·75	0·50-1·00	0·65 max.	0·25 max.	1·0 max.	55-65
Valve tappets, rollers	0·10-0·25	0·30 max.	0·20-0·60	2·75-3·50	0·30 max.	—	—	—	45 max.
Connecting rods, hand starter gears	0·25-0·32	0·30 max.	0·35-0·60	3·75-4·50	1·0-1·5	0·65	0·25 max.	1·0 max.	100 min.
Airscrew hubs, highly stressed connecting rods, bolts and nuts	0·22-0·28	0·30 max.	0·35-0·65	2·75-3·50	1·0-1·4	0·65	0·25 max.	1·0 max.	65-70
Bevel gear shafts	0·35-0·45	0·30 max.	0·50-0·80	3·25-3·75	0·30 max.	—	—	—	55-65
Cylinders	0·50-0·60	0·30 max.	0·40-0·75	—	—	—	—	—	45
Control levers	0·25-0·35	0·30 max.	1·20 max.	—	—	—	—	—	25-35
Crankshafts, connecting rods, airscrew shafts, hubs and bolts	0·28-0·35	0·30 max.	0·70 max.	3·00-3·75	0·50-1·30	0·30 max.	0·25 max.	1·0 max.	65-75
Struts	0·40 max.	0·35 max.	1·75 max.	—	—	—	—	—	35 min.
Axle tubes, struts	0·25-0·35	0·35 max.	0·45-0·70	3·0-5·0	0·50-1·50	0·50 max.	0·25 max.	1·0 max.	85-100
Fuselage and undercarriage parts, engine mountings, tail units and other major welded tubular parts	0·30 max.	0·35 max.	1·75 min.	—	—	—	—	—	30-35 min.
Valve springs	0·70-0·80	0·30 max.	1·0 max.	—	—	—	—	—	95-120
Spares, ribs, fuselage members, high tensile plate fittings	0·25 max.	0·30 max.	1·75 max.	0·20 max.	—	—	—	—	—
Spares and spare tension members, ribs, fuselage members	0·50 max.	0·30 max.	1·75 max.	—	—	—	—	—	—
Structural parts, fuselage	0·30 max.	0·30 max.	0·80 max.	0·80-1·20	0·15-0·30	—	—	—	45 min.
Struts and other high tensile tubular members	0·25-0·35	0·35 max.	0·45-0·70	3·00-3·50	0·50-1·50	0·50 max.	0·25 max.	1·0 max.	75-85
Canes	0·85-0·95	0·50 max.	1·7 max.	0·25 max.	0·60 max.	0·60 max.	0·35 max.	1·0 max.	—
Cylinders and cylinder liners	0·15-0·35	0·35 max.	0·65 max.	0·30 max.	2·5-3·5	0·30-0·75	0·25 max.	1·0 max.	60-70

providing necessary prestressing to reduce the maximum stress on loading. This part is also usually made of heat-treated chrome-molybdenum steel.

There are a few other airframe components for which chrome-molybdenum steel has to be employed, such as the brake-drum, certain control torque tubes, gunmounts in certain military aircraft, etc.

Next to chrome-molybdenum steels, the most widely used variety in aircraft is stainless steel. Although employed as long ago as 1920, stainless steel was not more generally adopted for structural parts till about 1930. Its corrosion-resistant properties coupled with temperature resistance make it particularly suitable for making engine shrouds and firewalls. These are usually made from steel stock of 0·3 per cent carbon and 13 per cent chromium. The same material is also used for exhaust stacks and collectors. A variety having 20 per cent chromium and 2 per cent nickel has been found most suitable for making machined fittings such as sockets, fork-ends and pins, eye-bolts, wing roots, wing-fixing lugs, turnbuckle levers, bolts, nuts and studs. In fact, a wide range of stainless steels are now in use in aircraft construction with different degrees of strength and physical characteristics (Table 2). Recently a whole turbine engine has been built of stainless steel except for a few components.

The material of the combustion chamber of this gas turbine engine is actually a modified inconel alloy containing Ni, 75; Cr, 14; Ti, 3·0; Al, 0·6 and Fe, 6 per cent. Rotors of gas turbines have been usually made of a temperature and corrosion-resistant alloy containing Cr, 16; Ni, 25; Mo, 6, and C, 0·08 per cent.

The Aircraft Engine

The aircraft engine is a complicated mechanism requiring quality alloy steels for many of its components.

There are few components in a reciprocating engine where the loading can be considered from a purely static aspect, and in general all parts have to be designed on the basis of the dynamic loadings imposed. These vary cyclically at a relatively high frequency and the range of stress may be sufficient in some cases to cause reversal of stress. The failure of any individual component can be expected, therefore, to result from fatigue rather than from direct overloading.

Components in the combustion zone operate under conditions of high temperature. Chemical attack caused by the burnt gases has to be considered. This feature is of great importance with the concentrations of tetraethyl lead found in high-octane aero-fuels, and trouble from this source was experienced on military vehicles during the war leading to major changes in the material.

Crankshafts

The stresses imposed on a crankshaft are a combination of bending and torsion, and the operating temperature is not sufficiently high to cause any modification in the temperature and mechanical properties. In the higher power aero-engines chrome-molybdenum steels of about 60 tons/sq. in. are employed. The surface is usually hardened to 700 V.P.N. by nitriding or induction-hardening. In lower power engines, where loadings are less arduous, the principal materials used are nickel-chrome-molybdenum steels of a strength of about 50 to 70 tons/sq. in. Surface treatments for hardening are not usually given to these shafts as it is not economical.

Connecting Rods

The connecting rod is another highly stressed component subjected to a variety of stresses. The shank has to withstand piston inertia loads which alternate in tension and compression together with combustion

TABLE 2 — NON-CORRODIBLE OR STAINLESS STEEL FOR AIRCRAFT COMPONENTS

Name of the aircraft component	Composition, per cent							Max. stress, tons/sq. in.
	Carbon	Silicon	Manganese	Nickel	Chromium	Titanium	Tungsten	
Inlet valves, throttle, control rods, carburetter parts and exhausts	0·15-0·35	0·150 max.	—	1·0 max.	12·0 max.	—	—	46-52
Bolts and nuts, undercarriage and engine mount fittings	0·25 max.	0·150 max.	1·0 max.	1·0 min.	16·0-20·0	—	—	55 min.
Medium and stressed plate fittings	0·15 max.	0·150 max.	0·70 max.	1·0 max.	12·0 min.	—	—	30-40
Valves	0·40-0·50	3·25-3·75	0·40-0·60	0·50 max.	7·5-8·5	—	—	—
Valves	0·30-0·45	1·00-2·50	1·5 max.	10·0 min.	12·0-16·0	—	2·0-4·0	—
Lightly stressed spares, ribs	0·20 max.	0·60 max.	1·0 max.	1·0-3·0	10·0	—	—	55-70
Medium stressed tubular members	0·15 max.	0·50 max.	1·0 max.	1·0 max.	12·0 min.	—	—	35-45
Streamline wires	0·25 max.	0·50 max.	1·0 max.	1·0-3·0	16·0-20·0	—	—	52-65
Highly stressed spare construction	0·25 max.	0·50 max.	1·0 max.	1·0 min.	16·0-20·0	—	—	—
Flexible wire rope for control wire	0·20 max.	0·20 min.	1·0 max.	6·0-20·0	12·0 min.	Present	—	35 min.
Highly stressed struts and amphibian undercarriage construction	0·25 max.	0·50 max.	1·0 max.	1·0 max.	16·0-20·0	—	—	45-50
Highly stressed tubular airplane	0·10-0·20	0·50 max.	1·0 max.	1·0 max.	12·0 min.	—	—	50-65
Fuselage engine mountings	0·20 max.	0·50 min.	1·0 max.	6·0-20·0	12·0 min.	Present	—	50 min.
Magneto contact breaker and instrument springs	0·27-0·32	0·50 max.	1·0 max.	1·0 max.	12·5-13·5	—	—	105-120
Springs	0·27-0·35	0·50 max.	1·0 max.	1·0 max.	12·0-14·0	—	—	95-120

compression loading and bending stresses due to the transverse acceleration of the rod. It may be noted that in combustion loading the material has to withstand shock loads due to detonation effects. Though for lighter aero-engine connecting rods are forged out of strong aluminium alloys, for high power units a 3·5 per cent nickel steel or a nickel-chrome-molybdenum steel (70 tons/sq. in.) is generally used. In fact, for the master rods which are subjected to even more severe stresses, a nickel-chrome-molybdenum steel heat-treated to 100 tons/sq. in. has to be employed. The disadvantages in using this high-strength material is the low ductility and low notch-impact strength. A material which would provide such strength and at the same time retain good ductility and impact strength will be most suitable for master rod forgings.

Valves and Valve Springs

Valves are usually made of nickel-chrome-molybdenum steels. The exhaust valve, of course, has to meet more exacting conditions than the inlet valve. The valve head must be stable under operating stresses at temperatures which may be as high as 750°C. and must resist corrosion and erosion by the products of combustion. For inlet valves an austenitic alloy forging having roughly 12 per cent chromium is employed. The valves are given a stellite coating to provide the necessary wear resistance. The exhaust valve is also made of an austenitic steel, but is coated with 80 per cent nickel, 20 per cent chromium alloy to a depth of 0·05 in. for building the required wear resistance.

The stress conditions in valve springs are predominantly of fatigue type and in addition to the normal stress variation supplementary stresses may be induced by surging effects in the coils of the springs. With few exceptions the material used is a 'patented' hard-drawn steel containing 0·70 to 0·80 per cent carbon. Shotpeening is often adopted to increase fatigue strength. Chrome-vanadium steel of 100 tons/sq. in. ultimate strength is an alternative material for valve springs.

Camshafts and Gears

The camshafts are generally made of case-hardening steels, the cams and bearings being surface-hardened. The steels include varieties of unalloyed mild steel or 5 per cent nickel steels.

Gears

By far the greatest number of gears are made from case-hardening steels. For most highly stressed gears, such as the propeller reduction gears, a 4 per cent nickel, 1·5 per cent chromium steel with a tensile strength of 80 tons/sq. in. has often been adopted. The use of nitrided gears is not so common in the aircraft industry, but it offers some attractions in respect of resistance to both fatigue and corrosion.

Conclusion

I have been able to give only a cursory survey of the use of alloy steels in aircraft construction. However, the survey would clearly indicate the importance of choosing materials very carefully for the construction of aircraft parts. With the vision of a rapidly growing aircraft industry in this country before us, I venture to put forth a few suggestions for the developments of suitable alloy steels for aircraft construction.

As emphasized earlier in the text of the paper, the desired performance in any aircraft can be obtained only by using *the* material which meets *all requirements* and not some substitute which is very nearly good. This means that a systematic approach should be made for the development of alloy steels in this country using materials available with us. The usual law of supply and demand may not apply in this case, and at least for a few years the government should come forward to give generous support for any large-scale projects for the development of special materials for aircraft construction. In the early stages of investigation, the large fund of knowledge provided by the Society of Automotive Engineers, the Institute of Metals and other similar bodies will form the basis on which to build a developmental project with a long-range view.

First preference, in my opinion, has to be given to the development of suitable nickel-chrome-molybdenum alloys which are capable of acquiring high tensile strengths without much loss of ductility and fatigue strength. Facilities for testing of fatigue strengths and other mechanical properties should be expanded in laboratories like the National Metallurgical Laboratory and the National Physical Laboratory where there are already some equipment to undertake such work.

Of equal importance is the development of corrosion and heat-resistant steels both for cold-working and heat treatment. Stainless steels are finding more and more use in aircraft construction and very soon they may eclipse other materials in this respect. The latest pulse jet engines call for very high strength austenitic steels for their construction, not to speak of the other manifold uses stainless steels are put to in aircraft. The stainless steels developed should lend themselves easily to welding operations and should withstand high temperatures if they are to be a success.

Of next importance is the study of various compositions of high-carbon and vanadium steels for springs, particularly valve springs, in aircraft. High fatigue strength and tensile strength are the important criteria for such materials.

Steels in aircraft is a vast subject and though I may not have succeeded in giving an exhaustive survey, I shall feel happy if I have at least given a glimpse of this vital problem before us. Development of such materials is indeed not a formidable task. With the combined effort of the steel industries of this country and the concerned national laboratories I can foresee nothing but a bright future for developmental work in alloy steels.

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