High-Strength Steel—Present Limitations

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Steel parts, heat treated to 260,000 to 280,000 psi, ultimate strength are now used on large aircraft at almost double the unit stresses permissible 15 years ago in similar parts of 150,000 to 170,000 ultimate. (T 24, ST)

Several years ago the American airframe industry became interested in the use of steel at higher strength levels than those previously accepted for structural or mechanical applications. Some companies became interested in special steels which were satisfactory at ultimate tensile strengths up to about 240,000 psi. Because this steel was generally available in aircraft quality and because its properties seemed attractive at still higher strengths, our work at Lockheed Aircraft Corp. was directed toward the use of 4340 steel at the 260,000 to 280,000-psi level.

Very little was known about such factors as fatigue, notch sensitivity, ductility or the effects of variations in heat treatment, machining, plating or other processing and fabrication operations.

Our investigations began with a few fatigue tests which indicated that, contrary to popular opinion, the ratio of fatigue strength to ultimate tensile strength at the high strength level was about the same as that same ratio as determined for the conventional lower strengths. In other words, the material was proportionally higher in fatigue properties. With such encouragement, the next step was to make an actual airplane part, heat treat it to 260,000 min. and subject it to fatigue cycles approximating the service conditions of that part on an airplane. The results were so good that it was decided to start an intensive program of study in the laboratory and to also consider the actual design of landing gears using steel at the 260,000 to 280,000-psi strength level. Detail studies were made of the redesign required for incorporation into the landing gears of our "Constellation" as well as for experimental planes being designed at that time.

Process Control for Aircraft Parts

In order to prepare correct processing control specifications, an intensified study of heat treatment and other manufacturing operations was necessary in order to insure the integrity of the fabricated parts. The details of heat treatment came first but, because of the many other processes needing close control, it was decided to put all the special requirements into one specification which has become fairly well known throughout the industry as the "Lockheed Process Bulletin 220 M".

Other factors which had to be determined were (a) how to machine steel at this high hardness, (b) whether weldments could be made by flash and pressure methods, (c) could parts be safely ground, (d) was there an increased susceptibility to hydrogen embrittlement and (e) could shot-peening eliminate the effects of slight decarburization. These and many other fabrication and processing problems confronted us.

It was found that better ratios between yield and ultimate strength could be obtained if produced more consistently by first normalizing at 1600° F. and then austenitizing at 1475° 1500° F. for a somewhat longer time than is usual commercial practice. Tempering is at 4 to 500° F., depending on the as-quenched hardness. Again, longer heat treating cycles are required to obtain consistent results than are generally used when heat treating to lower strength levels. These requirements have be

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quite controversial, but tests indicate that unless the heat treatment is performed as specified the resulting properties have not been consistently satisfactory.

Machining has been quite a problem but if sturdy equipment is available the heat treated parts can be machined. High surface speeds with carbide tools are recommended and produce a satisfactory surface finish. If high speeds (about 300 to 400 surface ft. per min.) cannot be used, a very low speed seems necessary — below 40 ft. per min. It is believed that the velocity of plastic failure in compression ahead of the cutting tool is the controlling factor in determining the optimum machining conditions.

Flash welds made with the same setting used for parts to be heat treated to lower strengths would not meet the quality requirements when the alloy steel is to be heat treated to 260,000 to 280,000 psi. This necessitated closer controls and slightly different operation cycles in order to produce satisfactory welds. Pressure welds seemed to be less critical and little difficulty was encountered in determining satisfactory welding conditions.

The fear of high surface stresses caused by grinding or by straightening led to the limitation of grinding after heat treatment to those areas specified on the drawings. In addition, if any grinding or straightening is to be performed those areas must be shot-peened, both to improve fatigue and to prevent cracking during subsequent plating or cleaning.

Some of these requirements are necessary because the tempering temperatures are so low that stress relief by heating is not very effective. Some relief can be obtained after severe operations such as grinding, by heating to 375° F., but it has been considered advisable to supplement this by peening and thus avoid the possible cracking of very expensive parts.

Limitations on Cleaning and Plating

For many years it has been known that susceptibility of steel to hydrogen embrittlement is somewhat proportional to its strength. Thus, cleaning and plating processes were expected to produce severe embrittlement in steel at the new high strength. In this we were not disappointed. However, the surprising thing was that certain plated specimens became ductile after baking at 375° F., while some remained brittle even after long periods of time at the same temperature. A number of processing variables seem to affect the ease with which the embrittlement can be relieved. These have been found to be (a) cleaning methods, (b) use of brighteners in the plating bath, (c) current intensity and (d) even the form of the current wave. It is suspected that the free alkalinity and temperature of the bath may also be factors.

This complex nature of the problem has led to the requirement that test specimens be placed in each load to be plated, at least until such time as it is certain that all the variables are known and controlled. At present, only the Lockheed Plant A-1 plating department and two vendors are permitted to plate any part at the high strength level. In addition, approximately double the usual baking time is specified.

Extensive tests have been performed in an attempt to determine the extent of the effects of the above-mentioned variables but so far the results are not very conclusive.

Surface Condition

Certain critical parts are required to be machined after heat treatment, in order to ensure freedom from decarburization. Other parts may be heat treated without subsequent machining. In some instances the highly stressed parts will be shot-peened. Furnace atmospheres have not been dependably controlled; one part was carburized which resulted in an unsatisfactory proof test of a welded assembly. At present it appears safer to permit some decarburization and peen the part rather than risk surface carburization. Thus far it is not known how much surface carburization, resulting in a slightly harder surface, can be tolerated but we suspect that even a very slight carbon differential can be deleterious.

Since peening has been depended on for restoration of fatigue properties of decarburized parts, it was necessary to learn the comparative effect of various amounts of decarburization and the ability of peening to benefit parts of various degrees of surface decarburization. It was learned that the damage in fatigue by decarburization was about the same whether the depth be 0.003 or 0.030 in. In other words, a little decarburization is just as bad as deep decarburization in its damage to the fatigue properties of steel heat treated to a high strength level. However, shot peening is very effective in almost completely restoring the life expectancy of the parts.

Inspection was another problem which arose. How could we determine the strength of the finished part? Since separate test pieces would have little relationship to a large part, one must rely almost wholly — except for the use of hard-
ness tests on the parts themselves — on the exacting control of processing. Since the relationship between hardness and tensile strength is not a straight-line function, and since the 260,000 to 280,000-psi strength is so close to the maximum hardness attainable in the steel, it is apparent that any relationship must be determined for each lot of steel. By tests on two heats of steel at about the highest and lowest hardness capabilities permitted by the analysis range, a near parallelogram of values was obtained and a hardness range established within whose limitations the material would have more than 260,000 psi. minimum. It is appreciated that the use of such a criterion will sometimes give us parts whose actual strength will be above the 280,000-psi level, but this variation must be accepted as a normal expectancy. This safe range differed slightly from published hardness data and is to be considered as correct only for 4340 steel to meet aircraft specifications.

My remarks have been intended to illustrate some of the problems encountered in the use of steel, heat treated to high strengths. As I have shown, many of them have been solved, others have been partially solved and some must be studied further. We feel that great progress has been made. Only 15 years ago Lockheed was required to redesign a landing gear strut to lower the strength after heat treatment to 150,000 to 170,000 psi because it was considered unsafe at 180,000 to 200,000 psi. The use of 260,000 to 280,000-psi steel has thus almost doubled the load-carrying capacity of components. In the present age of increased speed and efficiency of aircraft, this saving in weight becomes very important. Perhaps even the present strengths will be exceeded by new steels, since there are several now under preliminary study for use above 300,000 psi. tensile strength. One can hardly predict what the ultimate goal may be.

We, at Lockheed, have been content with S. A. E. 4340 steel for our present applications but know well that it is only an intermediate stage as airplane parts become larger and steels of still higher strength become available.