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PART 6

SURVEY OF LOW-ALLOY AIRCRAFT STEELS HEAT TREATED TO HIGH STRENGTH LEVELS

Part 6. Recommendations for Future Research Work on High-Strength Steels

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SYRACUSE UNIVERSITY

SEPTEMBER 1954

WRIGHT AIR DEVELOPMENT CENTER

NOTICE

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MATERIALS LABORATORY
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WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
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FOREWORD

This report was prepared by the Syracuse University, under USAF Contract No. AF 33(616)-392. The contract was initiated under Research and Development Order No. 614-13, "Design and Evaluation Data for Structural Metals", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. E. Dugger acting as project engineer.

ABSTRACT

The Appendix presents a number of suggestions for future research work on low-alloy aircraft steels heat treated to high strength levels.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

RECOMMENDATIONS FOR FUTURE RESEARCH WORK ON HIGH-STRENGTH STEELS

In the various sections of this report dealing with specific properties of high-strength steels many instances have been described in which certain intentionally or unintentionally applied practices may lead to deficient properties. The analysis of failure cases in Part 2, further revealed that such deficiences, and usually more than one deficiency, were present when a failure occurred.

There is a large volume of information available on high-strength steels. This information reveals that the possible sources of deficiencies and, therefore, of failures become more numerous as the strength of the steel increases. Furthermore, a distinct acceleration toward a different level of many properties is observed as the strength passes through the 200,000 psi ceiling. However, definitive data on any one specific property or group of properties of high-strength steels are rarely available and a fully systematic evaluation of these steels which does not contain many loopholes is not possible at present due to the lack of adequate data.

Considering the magnitude and importance of applications of 4340 and related steels, in general, and the future use of these steels at their highest strength levels, in particular, this lack of information regarding the effects of alloying, processing, heat treating, and stressing variables on most of their pertient properties is rather appalling.

The main recommendation for future work, therefore, comprises an initiation of an integrated over-all program for the study of a considerable number of pertinent properties of 4340 steel and a few competitive steels and the development of design data for these. This work should consider particularly the effects of commercial variations and limitations in carbon and alloy constituents, ingot size, steel-making and breaking-down practices.

This program should be particularly aimed at establishing the fact whether tempering temperatures between 500 and 700°F must be avoided in order to obtain the best possible performance. To date, the only definite indication of this 500°F (600°F) embrittlement is presented by a minimum in impact properties (Part 5-12, 29, 30, 32, 34, 42). In addition, the fatigue strength of smooth and notched specimens (Part 2-13) as well as the notch-tensile strength of large sections (Part 5-48) also appear to be lower in the above range of tempering than either at 400°F or 800°F. Particular attention, in this respect, must be paid to the effects of carbon content (Part 5-29, 30) and silicon content (Part 5-34) and to the effects of tempering time (Part 5-42). Such investigations should also clarify the structural reasons for any deficiency in properties resulting from tempering within the range of embrittlement.

Another particularly important task is believed to be a systematic and practically complete analysis of failure cases (Part 3) and the speedy distribution of such information. With new design criteria becoming necessary for high-strength steels the factual and educational value of accurate knowledge regarding the combination of factors which have lead in the past and which may lead in future to failure cannot be overemphasized.

Particularly important, in this respect, is the systematic study of hydrogen embrittlement which comprises a rather recently-recognized phenomenon, as far as high-strength steels are concerned (Part 1). While a number of systematic investigations on the hydrogen embrittlement of high-strength steels are under way, to date, these fail to cover the whole range, and particularly a number of practically important aspects of this problem. Among such partial problems which require particular attention, one concerns the factors which determine the recovery of hydrogen-loaded and especially electro-plated parts (Part 1-20, 22, to 26) and another one relates to the response of different types of test specimens to various hydrogen contents (Part 1-7 to 14). To date, no simple test is known which yields a lucid quantiative measure for both small and large effects of hydrogen embrittlement.

The present knowledge of the properties of high-strength steels clearly reveals that conventional design criteria will not prevent failures of structures in these materials. Just how the results of experimental laboratory projects are able to assist the designer in supplying the data required for safety is an unsolved problem. A cooperative program should be established, in order to forge ahead to a solution of this important problem.

Stress-concentration effects which result in low strength of a structural part are not well defined, at present. An exhaustive study of the numerous factors which determine the effects of a given stress-concentration factor on 4340 steel both under static loads (Part 5-2, 3, 5, 20, 21) and under vibrating stresses (Part 2-11 to 16) should therefore be made.

The effects of straining rate and testing temperature on the properties of high-strength steels are not clearly established. It appears, that they are of minor importance in the absence of hydrogen (Part 2-2, 10; Part 4-54 to 58; Part 5-4, 14, 22, 23, 30, 32). In contrast, the presence of hydrogen promotes a pronounced reduction of the ductility and, in the presence of stress concentrations, also of the strength as a function of the rate of straining or time of sustained loading, and to testing temperature (Part 1; Part 3-9 to 15). Information is needed particularly regarding the effects of speed in the presence of various controlled amounts of hydrogen and at closely controlled testing temperatures.

The general program for investigating the properties of the high-strength steels may be broken down into a great number of individual research projects. A selected list of such research which is considered to be most pertinent to date is presented and discussed below. In each series of tests the range of the investigation should extend slightly further than that of current interest, and, where possible, cover strength levels of 190,000 (± 10,000) psi, 210,000 psi, 240,000 psi, 270,000 psi, 290,000 psi and 310,000 psi, corresponding to tempering temperatures between 300°F and 900°F. In all instances, the results of tension tests and hardness tests, as well as chemical analysis, steel-making practice, ingot size and product size must be reported, in order to render the results of different studies comparable.

The following suggestions are classified in respect to the main variable or variables involved and list those properties which are primarily affected by them and the study of which appears particularly desirable.

The effects of the carbon content are of particular significance for design properties. The variations in tensile strength, and particularly in yield strength due to different carbon content increase as the tempering temperature decreases (Part 4-18, 22, 24, 25, 27, 28, 29). It may be necessary, therefore, to use different tempering temperatures for different carbon ranges if the present practice of specifying primarily the hardenability is maintained. This may lead to large variations in notch-strength characteristics (Part 5-28, 29, 30). It also appears that the relation between Jominy hardness and actual properties of heavy sections depend upon the carbon content and that this may result in undesirable property variations in parts having variable section thickness

Such information is particularly needed for the 4300, the vanadium-modified 4300, and the silicon-containing series of steels.

In regard to the effects of various alloying elements the mutual replacability of nickel, chromium, manganese, molybdenum, and vanadium in the range of high hardenability and carbon contents of 0.3 and 0.4 percent respectively should be studied (Part 4-30, 5-35). For such work one rather large section size should be selected.

The effects of silicon must be established in various respects, (Part 4-31; 5-34). One important problem is whether silicon additions will compensate for the undesirable effects of varying carbon contents on tempering at about 400°F.

Aluminum additions greatly determine the impact strength and notch-tensile strength of high-strength steels (Part 4-33; 5-31, 32). It is not known, however, whether any other properties such as fatigue strength and transverse tensile strength are also affected by aluminum additions and by aluminum retained in solid solution.

A large and complex problem group relates to the effects of ingot size and breaking-down practices. It is now clear that static stress-concentration effects become more pronounced as the as-processed section size increases (Part 4-37 to 43). Systematic studies of such effects are needed, extending particularly also to fatigue strength and transverse strength.

There seems to be considerable arguments about effects of overheating. While it is known that a small austenitic grain size is important for tool steels and carburized steel the few test data available for high-strength steels, in this respect, present a rather confusing picture (Part 5-39). Further work should aim at establishing whether such effects exist, particularly on the static, impact and fatigue strength of notched bars.

A large number of problems is associated with the properties of heavy sections (Part 1-22; Part 2-25, 26, 27; Part 4-37 to 45; Part 5-46 to 52).

For application of the high-strength steels their response to hardening in large sections is of paramount importance. While there is a considerable amount of information available, on this respect, of the as-quenched section size (Part 4-42 to 45; Part 5-50, 51, 52), it is not sufficient for evaluating this effect.

Because of the usual methods of procuring tension test bars, the first indications of slackquenching and their effects on static, impact, and fatigue properties are not known. More extensive and systematic data on the properties of sections of various thicknesses but identical material should be procured for the most important high-strength alloys. These studies should be correlated with those of minimum-size sections subjected to various cooling rates and of Jominy-hardenability testbars (Part 4-15, 16).

The properties of heavy sections tested full size are practically unknown. Notch strength (Part 4-37, 42; Part 5-47, 50) and fatigue strength Part 2-26) decrease with increasing size of the as-tested section. This true section-size effect appears to increase as the strength level increases and more information on this subject is badly needed.