INTRODUCTION

By H. W. Gillett[1]

When a writer of fiction lays the scene of his story on Mars, he recognizes that differences in environment must be met by different materials. He not only describes the Martians themselves and the flora and fauna of the planet as oddly different from the living things we are accustomed to on Earth, but he also supplies the Martian engineer with materials of construction of an entirely different character, fitted to withstand new conditions.

Some of the environments for which metals are being demanded by our Earthly engineers, for service at very high and very low temperatures, are as variant from those under which we normally draw our conclusions as to the behavior of metals, whether the conclusions be based on observation and experience or on laboratory testing, as are the conditions on Mars and on Earth. That different materials of construction must be found for service at extreme temperatures and that there will be a limit of serviceability of many materials employed for construction at normal temperatures, is not surprising.

The engineer knows that he could do many things more cheaply and efficiently if he could operate at greatly elevated temperatures. But when he reaches temperatures such that steel and most other alloys act very much as lead does at room temperature, his problem ceases to be simple. He calls upon the metallurgist and the testing engineer to provide him with new materials, with precise information on their properties at high temperatures, and to tell him, too, at just how high a temperature he dare use the materials with which he ordinarily works. While this situation has long existed, it is only recently that the new materials and the new data demanded by the engineer have been forthcoming in any great measure. But the engineer is insatiable; like the tiger in the zoo after a taste of blood, he licks his chops, and roars for a full meal.

Seven years ago, in 1924, the demand for information on high-temperature properties of metals brought the American Society of Mechanical Engineers and the American Society for Testing Materials together in a Symposium in which the then available data were presented and discussed. The importance of the subject was so great that there was established, as a result of that first Symposium, the Joint Research

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Committee on the Effect of Temperature on the Properties of Metals, with representatives from both societies. Its purposes are to foster study of the subject, to facilitate exchange of technical and engineering information on it, and to carry out research work on fundamental problems within the field covered by its activities. All these purposes are being fulfilled by work now under way.

The publications of the societies since 1924 have recorded, in papers and committee reports, the work accomplished by and sponsored by the Joint Committee. While the Joint Committee probably was the pioneer in concerted action in this field, engineers and scientists all over the world, spurred on by economic demand for information, have attacked the problem. Though the known data are still meager in comparison to the demand for them, such progress has been made that the time was evidently ripe for a summation of the present pressing demands of the engineer, and of what the metallurgist has produced toward meeting those demands. The Joint Committee and the sponsor societies therefore arranged a second Symposium on the same topic, the papers and discussions presented making up the present volume.

If those acquainted with the cost of the equipment and the tedious and protracted nature of the tests required for precise determination of the high-temperature load-carrying ability of metals will glance through this volume and estimate how great has been the cost of obtaining the data contributed to the Symposium, they can realize how vital the subject is to the engineer.

The papers herein are largely compilations of data from many sources, domestic and foreign, but compilations by experts qualified to appraise and interpret the data of others as well as their own. The subject has been divided into two general sections, one dealing with the Engineering Trends and Requirements for Metals at High and Low Temperatures, the other with the Properties of Available Metals for High- and Low-Temperature Service. This volume, then, deals with the subject primarily from the engineering point of view.

The technical question of methods of research and testing for high temperatures was not dealt with, chiefly because of lack of time at the meeting or space in this volume, but also because that subject is constantly under consideration by the Joint Committee, and it is regularly dealt with in the committee reports. It is discussed in many of the 1200 references appearing in the bibliography published in 1928 and the supplement published in 1931 as prepared by the Joint Committee and published by the A.S.M.E., and in the bibliography contained in this volume.

Within the engineering fields covered by this Symposium, the authors of the papers have had the task of summarizing the information contained in the extensive literature, of appraising it critically, and of adding unpublished information. Not only are the more formal papers of interest, both as to the data presented and its critical appraisal, but the copious discussion has added much in further unpublished information and wise comment. The Symposium was especially planned to bring out discussion by presenting each session's papers in one unified abstract, by others than the authors, so as to give time for the discussion. The special thanks of the Committee are due all the authors not only for the labor of preparing their articles, but for the promptness with which they did it, which allowed the complete set of papers to be distributed long enough before the meeting to elicit the desired discussion.

The keynote of the whole Symposium is found in the opening paragraph of the first paper, where Kerr points out that the engineer, who now states immediate requirements which are still a bit ahead of what can be supplied, will make those requirements still more stringent in the future. It seems that the task of the metallurgist will be never-ending. His task is not over when he does find materials of the required properties, for as Kerr points out in the body of his paper that they must have good fabricating properties, and in the final paragraph, that they must be cheap enough to make it good economics to use them.

Yet first cost does not deter the user of alloys at high temperature, if their use means an over-all saving. Several of the papers refer to large-scale use of an alloy containing 66 per cent nickel, 20 per cent chromium, and the inclusion of data on the platinum metals in this Symposium seems inconsistent to no one, even though it is the engineering point of view that is being considered.

Bailey comments on the need for the elimination of the "mild steel complex," and the willingness to utilize new alloys aimed to meet a particular problem. Comment is made on the fact that very few of the alloys listed in the 1924 Symposium as most promising for high-temperature service have survived in 1931, but have been displaced by still better ones. While chromium and nickel are the vital elements in such a large proportion of the alloys mentioned for various purposes that they clearly overshadow all the other alloying elements in importance, the tendency toward embrittlement of the otherwise well thought of "18 and 8," as well as of the straight iron-chromium alloys, and the great amount of effort being put on the elimination of this fault leads to the belief that some modification is likely to be met in such alloys. Comment on the marked and specific benefit conferred upon the high-temperature properties of carbon and various alloy steels by the introduction of molybdenum or tungsten, particularly the former, occurs in so many of the papers that increased commercial attention to and use of molybdenum alloys is clearly presaged.

Now that it is known that the nitriding steels and the nitride case have excellent high-temperature properties, they too will call for more attention. Brief reference to "Konel," which bids fair to show outstanding creep resistance, brings cobalt also into the picture.

One thing is very obvious in all the papers; everyone expects a change in the alloys used for almost any high-temperature service. Boegehold and Johnson indicate that the automotve engineer would be receptive to beryllium-aluminum piston alloys when they are made available for his use, and they definitely prophesy the passing, for severe service, of the present group of babbitt metals and their replacement by new types of bearing alloys.

Anyone who fears that the national technical societies which are standardizing materials and methods of testing, and putting out specifications and recommended practices, are causing stagnation, need only read this Symposium to realize through what a state of flux the development of an alloy must pass while it is in the research stage, prior to the establishment of purchase specifications, and how far from sacred even an accepted specification would be if it were not promptly revised to represent the best information on the subject.

That much further research is needed is brought out by the fact that almost all the high-temperature data on cast iron and on many aluminum and copper-base alloys, for example, are based only on "quick-pull" tension tests.

Yet how far the quick-pull test may come from representing the long-time facts is clearly shown by the curves on pages 356, 529 and 562 as well as by comments on many other pages. Spooner and Foley find enough data obtained by long-time tests on the low-alloy steels so that they discard entirely all quick-pull tests as of too little value to cite. However, the fact is brought out by others that, up to temperatures where strain hardening effects are rapidly removed by the annealing effect of the temperature, or where recrystallization of a cold-worked metal occurs, the short-time data, properly correlated with some creep data, do give useful information.

While many papers express an implied or an explicit desire for an accelerated creep test, there is a general feeling that the "little knowledge" obtained by the various short-cut methods so far brought forward, "is a dangerous thing," and because such methods purport to give data truly representing long-time behavior, the terminology used is likely to mislead the engineer into taking the data for design purposes without the necessary grain of salt. The warnings of Bailey, page 219, and of Chevenard, page 267, that it is still prudent to draw conclusions only from truly long-duration tests indicate that careful foreign thought is in agreement with the cautious attitude of most American investigators.

It is pointed out that even with the most careful testing procedure it cannot be assumed that the results of tests of a single heat necessarily truly represent the characteristics of all material of that composition. For example, although the 80 per cent nickel, 20 per cent chromium alloy for electrical resistors has been accepted for years, the life of furnace resistors has been multiplied many times during the past decade due to more careful and uniform methods of production rather than to any change in composition. That foundry practice governs the high-temperature service of cast alloys as much as does the alloy composition is clearly brought out by Bull and by the discussions of McCormick and Brown.

The engineer's responsibility to design his parts with due regard to the requirements of thermal expansion, if he is to avoid warpage, is clearly brought out by these writers, by Brown and especially by Mochel, whose assembly of expansion data from scattered sources will be a great convenience to the engineer.

Realization that large crystal size, as in a cast structure as compared with a forged structure, is advantageous for service at the higher temperatures emphasizes the fact that one must not be too ready to jump at general conclusions in regard to high-temperature performance on the basis of the analogies built upon room-temperature experience.

Care has to be taken not to draw too definite conclusions as to engineering design from laboratory tests, unless it is known certainly that the service conditions are adequately represented in the tests. Especially from Dixon's paper it can be seen that the operating engineer is normally far from precise in his knowledge of the exact temperature and stress he imposes on his structures. If in service the temperature once runs up, without the engineer's knowledge, into a region that causes rapid flow or an embrittling effect, his report of service on the basis of what he conceives to be the average and maximum conditions of service may be highly misleading. Especially where corrosive conditions are present are laboratory tests of doubtful application. A slight change in sulfur content of the gases bathing a part in high-temperature service may vastly alter the performance of an alloy. This was not intended as a Symposium on corrosion, but the topic would not down, and it crops up in paper after paper, disputing the limelight with the creep properties.

Again, the type of laboratory test required to give data of sufficient precision varies with the service in view. For turbine design where creep must be kept below 0.01 per cent per year over a period of perhaps twenty-five years, under the penalty of serious loss of efficiency in a design that has to allow extra clearance to provide for creep, no precision of test yet attained is good enough to satisfy the engineer. On the other hand, one who has to design a rabble arm can quite confidently utilize data of a low degree of precision. The tendency of some workers to refer to a "creep limit," based on their own requirements and the precision of their particular set-up, complicates interpretation of published data. In so far as possible the data cited in the Symposium have been related to the precision of the test method so that the reader may not be misled.

As Chevenard points out, increasing doubt is being thrown on the existence of anything that can properly be termed "a creep limit" so that comparison is now more commonly made on the basis of some defined rate of creep, or of no perceptible creep within a certain precision of measurement.

Designing engineers should be a bit patient with the testing engineer. Even though the latter cannot yet always give the former a design figure that can safely be used directly, it should be remembered that the relation of service performance at room temperature to the standard tension and other acceptance tests, determined by many decades of correlation after fair refinement in test methods was secured, calls for certain factors of safety that vary with the type of service. While the testing engineers are sifting their methods and slowly coming to some agreement on them, they may only be able to place a group of alloys in the correct relative order and to indicate the general order of magnitude of safe and unsafe loads and temperatures. Even that information is much better than nothing.

The daring or the foolhardy engineer who, in desperation because of the lack of exact data, takes a chance, since, as McVetty states (page 509), design cannot wait for settlement of all questions, has also contributed to progress, for when he is lucky, and the venture has no disastrous result, it spurs the testing engineer on to more careful determination of properties at higher temperatures than he has thought needed consideration, or else makes him active in proving to the designer that the alleged conditions of service were more severe than was actually the case.

In no field of engineering will there be more rapid utilization of materials of proven suitability to withstand still more severe service. One temporary difficulty is that the materials are still products of specialty rather than tonnage production, and production economies that will bring the cost down so as to justify wider use are difficult to institute when the most desirable composition and the proper test methods for evaluation of properties are still in a state of flux. Development costs will still have to be shared by the producer and the user who must have a "tailor-made" product to solve his difficulties.

There is a vast amount of work yet to be done, too huge to be handled by any single producing or consuming firm. It is clear from this Symposium, as it has been from the inception of the Joint Committee, that only by cooperation, free interchange of information (even of a type that in fields of less import in regard to life and limb of the ultimate user might be properly regarded as confidential) and the interweaving and interpretation of the threads of scattered information being spun by research laboratories the world over, can real progress be attained.

Long before the writer became a member of the Joint Committee, he admired the spirit of the cooperating societies, firms and individuals, for the firms and organizations with which many of the past and present members are connected have shown a most forward-looking attitude in exchanging information and in allowing their laboratories to perform very expensive tests on whatever part of the cooperative program was assigned to them, pooling all the data. Many firms not directly represented on the Committee have also cooperated whole-heartedly and unselfishly. While there is little formal cooperation among different countries in this work, yet workers in each country owe a debt of gratitude to their foreign friends for the publication of results. There are few fields of engineering or metallurgy in which workers follow as closely and utilize as promptly the results of foreign investigations as in this field of high-temperature properties. The inclusion of papers in this Symposium by English and French engineers who are pioneers in this field is only one sign of the international interest in the subject. Active international cooperation would certainly be welcomed and participated in by American workers.

It is the hope of the Joint Committee that the assemblage of data and opinions into this Symposium will prove a service to all interested in the effect of temperature upon metals, and that by pointing out the many serious gaps that still exist, it will encourage the collection and publication of the still much-needed but lacking information.

The Committee believes that still more active cooperative effort is demanded by the situation, and hopes to institute a thorough laboratory study aimed to fill some of the gaps that are unlikely to be filled by private, individual effort, to bring about more rapid codification of test methods, and to produce a better understanding of the fundamental phenomena of creep, fatigue, corrosion, embrittlement and other modes of high-temperature failure. To this end the interest, cooperation and support are solicited of all to whom this field of endeavor is of importance.