fatigue limits of smooth and notched specimens having similar surface preparation in the test section.

5 No "heating effect," of the sort reported for alloys RC 55 and RC 70 when subjected to fatigue stressing, was observed in the RC 130B or Ti 140A titanium alloys investigated.

6 Failure by fretting fatigue appears to be a more serious problem in the titanium alloys than in other commercially available structural metals.

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Discussion

L. P. Tarasov.[5] The authors show clearly the importance of the physical condition of the surface of titanium alloys with respect to their fatigue properties. By expressing this physical condition in terms of the hardness and roughness of the surface, they represent the fatigue limit as a simple function of these two variables. However, the discrepancy between the calculated and experimental fatigue limits, given in Table 3 of the paper, is large by comparison with the corresponding 95 per cent confidence ranges in an appreciable number of instances. This means that, although surface hardness can have a considerable effect upon the fatigue properties, the nature of the processing operation resulting in that hardness cannot be neglected. Differences in residual stresses and in the degree of cold-working, not shown up by corresponding hardness changes, such as those mentioned by the authors, may be responsible for the discrepancies mentioned.

The importance of the processing operation as distinct from the resultant surface hardness is well illustrated by the data now available for ground test bars. In the present work on unnotched bars, grinding caused a slight drop in the surface hardness of RC 130B and the fatigue limit was correspondingly low (Series 5), but in the case of Ti 140A, there was apparently no change in surface hardness, and the fatigue limit was in line with the hardness, as shown by comparison with the electropolished specimens (Series 3). On the other hand, Demmler, Sinnott, and Thomassen[6] recently found that under their grinding conditions the surface was hardened to a marked extent but the fatigue properties were greatly lowered. Here an appreciable increase in surface hardness was associated with a decrease, and not an increase, in the fatigue limit. Thus, at the present state of knowledge, it is doubtful that surface hardness can be safely used to predict the fatigue limits of titanium alloys except in a very general way. In this discussion, the possible effect of surface roughness has been ignored since it is relatively small according to the authors' data and would not affect the argument.

Series 1 and Series 9 were prepared in much the same manner except that circumferential scratches were introduced into the latter. Do the authors have any explanation for the considerably softer surface of the Series 9 bars?

A fuller description of the processing conditions would be most desirable in view of their obvious importance, both to other experimenters and to those who are concerned with the production of titanium parts. The feeds, speeds, and cutting fluids used in machining and grinding are among the factors that should be mentioned since they may have a profound effect fatiguewise. The authors have succeeded in grinding titanium without any adverse effects upon its fatigue properties, and the conditions should be stated in detail since the ones used by Demmler were responsible for a decided drop in fatigue properties. Granted that the authors say something about their grinding conditions, but it is not nearly enough since feeds and speeds are not mentioned, and only the relatively few people who are fully conversant with titanium grinding will recognize that a vitrified bond wheel of medium grit size was used with an active grinding oil developed for this purpose. The writer raises no objection to the use of brand names in engineering literature when it is necessary to pin-point the process, but does not believe that this should be done to the exclusion of at least a general description of the products involved.

More information about the surface roughness and the direction in which it was measured also would be welcome. The authors point out that the contour of the surface as well as the depth of the roughness may influence the fatigue properties, but they neglect to take into account the lay, i.e., the directionality of the surface irregularities. The lay is stated for some of the processing methods while for others it has to be guessed. There is some reason to believe that circumferential scratches will lower the fatigue properties of cantilever-beam specimens more than will axial scratches of the same depth and contour. Thus the fatigue limits for the Series 1 processing, which resulted in axial lay, may be somewhat higher than they would have been if the lay had been circumferential, as it apparently was in all the other series with the possible exception of the electropolished specimens.

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[6] "The Fatigue Properties of Some Titanium Alloys," by A. W. Demmler, M. J. Sinnott, and L. Thomassen, ASTM Preprint 72, 1955.

The authors have found that K_f was roughly the same as K_t for the ground notches but that it was somewhat lower than K_t for the cold-rolled ones. If it can be assumed that cold-rolling strengthened the notched and unnotched bars to an equal extent, the relatively higher values of K_f found for the ground notched bars might be due to some difference in the grinding action between the notched and unnotched bars. For example, it is possible that the grinding scratches were deeper in the notches and hence had a more pronounced weakening effect. Longitudinal sections through the test bars would show if there was any significant difference in the scratch depth.

Author's Closure

The authors wish to thank Dr. Tarasov for his detailed discussion of the present paper which emphasizes several important points. The authors are in agreement with Dr. Tarasov's view that the fatigue limit, hardness, roughness relation presented should be considered as a first approximation to the problem and that it could be further refined by including, for example, the surface residual stress as a variable. Unfortunately, a simple, accurate, rapid, and nondestructive means of determining residual stress in titanium was not and, in fact, is not yet available, so that the treatment of this factor in the present work can be qualitative only. Recent experience with additional titanium alloys suggests, however, that residual stress begins to contribute significantly to fatigue behavior only when the hardness is 420 Knoop or more.

Relative to the grinding operation, the specimens were "plunge-" ground on a cylindrical grinder using a contoured silicon-carbide wheel at a speed of 5000 surface feet per minute. Very light cuts were made by hand feeding and an average of no more than 2 to 3 ten thousandths of an inch per minute were removed from the surface. In no instance during the present experiments was the surface metal found to be significantly hardened by the grinding operation. Any such effect if present must have been confined to a surface layer the thickness of which was less than the depth of a Knoop hardness indentation (approx. $^1/_{10,000}$ inch.)

With regard to the softer surface of the Series 9 bars (Ti 140A) it is believed that two factors contributed to this effect; (*a*) the circumferential scratching method used removed the outermost layers of severely cold-worked metal left by machining and (*b*) approximately two thousandths of an inch additional metal had had to be removed from the "scratched" surface by electropolishing before hardness readings could be made free from interference with the roots of the scratches.

The surface-roughness readings were, in all cases, taken with the tracer head of the profilometer traveling in a direction circumferential to the test section. It is believed, however, that the roughness readings indicated in the table are those which would have the greatest influence on fatigue behavior since they represent roughness perpendicular to the principal fatigue stresses.