DISCUSSION

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The authors have continued their series of valuable contributions to the store of information in the literature on rolling contact fatigue. The unique data on pyroceram ball failures are particularly interesting.

On the basis of tests at relatively high stress levels as regards design stresses the authors emphasize the importance of static hardness as a material property qualitatively correlating with the 10 per cent fatigue life. In so far as plastic deformation in rolling contact relates to fatigue, could the authors comment on the observations made by Drutowski [4] wherein the influence of percentage of retained austenite on plastic deformation in rolling is emphasized in contradistinction to static hardness at stress levels nearer design levels (below 500,000 psi)?

It is reported that unpublished fatigue data on full scale bearings agree in general with the data of Table 3. Could the authors give any more information regarding these data?

Plastic deformation in rolling contact even at room temperature is a cumulative phenomenon enhanced by the complex cycle of stress created by the rolling action [5]. The rate of accumulation is initially very rapid for high load levels [6]; however, for lower loads the initially slower but more steady rate of accumulation into millions of stress cycles has special significance with regard to progressive fatigue failure. In one sense it denotes an intensification of residual stresses [7] which arise as a result of elastic accommodation of the restricted incremental flow.

Akaoka's data [8] suggest that stability or resistance to plastic deformation under the complex cyclic loading due to rolling, and not indentation, is a criterion of material suitability for fatigue endurance in rolling contact. In his tests with steels of the same hardness, mechanical work or forging ratio was the dominant factor. Therefore, it does not follow that resistance to static indentation is a sufficient index of fatigue resistance over a full range of applied stress and material conditions.

Finally, how are the photomicrographs in Fig. 12 oriented with respect to the surface of the ball and the direction of rolling?

Additional References


Authors' Closure

The unpublished fatigue data on full scale bearings referred to by Dr. Moyar were obtained by the Marlin-Rockwell Corporation and presented in [9]. These data summarized in Fig. 13 were obtained with four hardness levels—Rockwell C-59, C-60.4, C-62, and C-63. SAE 52100 steel, 207 size bearings running under a 1750-lb radial load were used. The results shown in this figure substantiate that rolling-contact fatigue life increases with increasing hardness.

Drutowski and Mikus [4] investigated the effect of per cent retained austenite on rolling friction. Specimens of hardened 52100 steel were prepared with amounts of retained austenite from 0 to 18.4 per cent. The hardness of these specimens varied from Rockwell C-58 to C-64. While hardness is a measure of the resistance of a material to permanent deformation by an indenter, elastic limit is the minimum stress required to permanently deform a material. The measurements taken [4] revealed an inversion between elastic limit and hardness. It was found that, with retained austenite levels up to 3.9 per cent, the elastic limit remained approximately constant. However, when the structure contained 7.4 per cent or more of retained austenite, the elastic limit fell off drastically. This occurred despite the fact that the specimens with the 7.4 per cent retained austenite had a Rockwell hardness of C-62, while the specimens with 0 per cent retained austenite had a Rockwell hardness of only C-58. This inversion between elastic limit and hardness is also indicated by data compiled by Sachs, et al. [3, 10], Muir, et al. [11], and Grobe, et al. [12]. Since it is apparent that a correlation does exist between rolling fatigue life and hardness, it follows that a similar correlation with elastic limit cannot exist.

Akaoka [8] in his fatigue studies used four groups of cylindrical specimens made out of the same alloy but each from a different heat of material. Specimens manufactured from three of the heats had the same forging ratio while a fourth had a lower forging ratio. All four groups of specimens had different mean lives, the shortest life being exhibited by the group having the lowest forging ratio. It should be pointed out, however, that bearing steels of the same chemical composition but from different heats of material will give significantly different lives [13]. Therefore, from these data, no valid conclusions can be reached as to the effect of forging ratio on rolling-contact fatigue life. Suppose, however, forging ratio is an important factor influencing fatigue life and eventually an ultimate forging ratio for bearing manufacture is achieved. Then to what hardness should these bearings be tempered? Although the data reported herein showing the correlation between material hardness and fatigue life were obtained from balls manufactured by standard forging techniques, the authors do not believe it presumptuous to conclude that this relation would exist with other forging ratios which may be used to manufacture bearings.

![Fig. 13 Summary of rolling-contact fatigue lives at four hardness levels of 52100 steel, 207-size bearings; radial load 1750 lb (data from ref. [9])](https://fluidsengineering.asmedigitalcollection.asme.org/doi/abs/10.1115/1.3650248?journalCode=jobe)
In answer to Dr. Moyar’s last inquiry, due to the high magnification (X 25000) of the photomicrographs in Fig. 12, the orientation of each micrograph with respect to the surface cannot be determined with any degree of certainty. Initial cracks as shown in Fig. 12(6) usually appear in the subsurface zone of resolved shear stress nearly parallel to the surface and then tend to propagate in a plane approximately 45 deg to the surface. The method of crack propagation from this initial stage requires further study.

Additional References