THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

ON THE DEVELOPMENT OF FAILURE DURING THE FATIGUE TESTING OF TORSION BARS

by

K. Brummitt, B.Sc

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SUMMARY

The effect of cyclic stressing on the torque characteristics of torsion bars has been studied by measuring the torque developed by a given deflection at frequent intervals during the life of torsion bars subjected to cyclic stresses in the range 600 - 1000 N/mm^2 from zero initial stress. In each case the bars retained their load characteristics for the greater part of their lives, loss of load bearing capability being rapidly followed by complete failure.

From the results of these tests it is clear that in fatigue failure significant loss in load on a spring is unlikely to occur before failure is imminent.

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1. INTRODUCTION

Despite the onslaught of the electronic revolution and the mighty microprocessor, springs are still found in a vast range of applications. Because of the wide variety of applications spring failures can range from irritating, through inconvenient and embarassing to disastrous. Equally there are instances when it is important to know when a spring has failed. There has been some worry that it might be possible for a spring to survive for a considerable period of time despite the presence of fatigue cracks of sufficient size to affect the functioning of the spring i.e. alter the spring rate.

To obtain information in this area a study has been made of load/time history of torsion bars under cyclic loading conditions in order to follow the failure process.

Much work has been devoted to the study of the initiation and propagation of fatigue cracks by various techniques and the stages involved in failure are now well understood. There are three basic stages in the development of a fatigue failure. The initiation of a micro crack, the growth of a microcrack along a crystalographic plane to the macrocrack stage and the growth of a macrocrack in a direction normal to the maximum tensile stress at the crack tip. The duration of each stage of failure can vary considerably and it is not always easy to predict this for real components. For instance fracture mechanics could be used to predict the size of crack which would lead to fracture of the spring but only in heavy springs are plane strain conditions even approximated and therefore the crack size would be over estimated by this approach and a larger propagation time would be predicted than would occur in practice. It is because of this type of difficulty that designs for components that have to withstand fatigue conditions are still normally based on practical test data.

2. EXPERIMENTAL PROCEDURE

Test specimens suitable for use with the Schenk torsional fatigue testing machine were machined from En 45 bar then hardenend and tempered to 460 HV 20. The gauge length and shoulders of the specimens were then polished using a Morrison type polishing machine using successively finer abrasive papers down to 00. The surface of each bar was then carefully examined under a low power binocular microscope to ensure than no flaws or other discontinuities remained on the gauge length.

Testing was carried out on a Schenk PWXN 80 mkp torsional fatigue testing machine. Test bars were prestressed to 1000 N/mm^2 twenty times by turning the machine over manually before the machine was adjusted to give the normal test stress range. Load measurement was by means of an integral calibrated torsion bar provided with an extension arm to facilitate measurement of the deflection of the bar by dial gauges. During testing the machine was stopped at regular intervals and the torque transmitted by the test specimen at maximum and minimum deflection was measured. This enabled the loss of torque with cyclic stressing to be determined. Additionally each time the test was interrupted the surface of the bar was examined for signs of fatigue crack formation. In early trials the test bars were removed at intervals for inspection with a magnetic crack detector. This practice was discontinued since no cracks were found by this technique that had not already been detected by a loss of transmitted torque, and the practice of removing the bar and subsequent resetting of the machine clearly introduced some variability in applied stress during the test run.

After failure the fracture surfaces were examined to ensure that the origin of the fracture was on the gauge length of the test bar and had not originated from any notable discontinuity such as a corrosion pit.

3. RESULTS

The results of the torque monitoring during the tests can be seen in Fig. 1. The behaviour of the test bars was consistent in that for each case the transmitted torque remained constant for most of the life of the bar. Close to the end of the test the transmitted torque dropped very rapidly and failure immediately followed. Variations with stress and scatter in results appeared to be related only to the number of cycles, endured before a load loss occurred.

Examination of the bar surface for signs of cracking invariably showed nothing until deterioration of the bar started to show up on dynameter measurements. Detection of the growing crack was then aided by the emergence of black oxide particles presumably magnetite from the crack. Although the irregular shape of the growing cracks preclude accurate measurements of the crack length, on several occasions rough measurements of the crack length at the surface with endurance were made. In each case the growth in crack length was approximately linear with endurance and reverse extrapolation in each case suggested that the crack had originated immediately before the dynomometer readings began to fall.

Examination of sections taken from the bars showed that the structures consisted of a uniform tempered martensite and that the preparation of the surface had been adequate to remove any decarburised layer or oxide penetration that might have been formed during heat treatment.

4. DISCUSSION

From the results obtained in these tests it seems clear that the greater part of the life of the test bars was taken up by the initiation of a microcrack and its propagation to the macrocrack stage. Once a crack of macroscopic dimensions appeared the subsequent life of the bar was short.

Certainly this result is useful from the design viewpoint since it indicates that the period during which a loss in load bearing ability was recorded is unlikely to be outside the normal confidence interval for fatigue results.

The apparent linear growth of the fatigue cracks with endurance is at first sight anomanous since the rate of crack growth might reasonably be expected to increase with the increased stress concentration created by the larger crack. As however the crack is growing in more than one dimension the area of the crack is increasing by a greater amount. This is not the total explanation however as although overall the crack length at the surface appeared to grow in a linear manner, observation of the propagation of the macroscopic cracks showed that the progress was in fact intermittant remaining apparently fixed for a period followed by sudden rapid growth often accompanied by an audible click. This observation can readily be understood if it is assumed that the material is essentially ductile, a fatigue crack will then propagate until the stress concentration at the crack tip is equal to the fracture toughness of the material at which point fracture of the material will take place. If however, this occurs in a ductile manner it is possible for the crack tip to become blunted by plastic deformation, the increased crack tip radius has the effect of lowering the stress concentration at the crack tip and halting the fracture. The stress concentration is, however, large enough for a fatigue crack to initiate rapidly at the root of the notch created and restart the cycle. This mode of macroscopic crack growth has been described by Wood.(1)

The comparatively short duration of the final stage of failure, that is the propagation of a visible macrocrack, is at variance with much practical engineering experience in other fields where macroscopic cracks have been observed to grow slowly over many years, in airframes and locomotive bogie frames for example. This is most probably due to the difference in stress involved and also the finish on the component. The test bars used for these tests were highly stressed with a constant stress amplitude, many engineering components operate at lower irregular stress and crack propagation therefore could reasonably be expected to be a slower process.

As springs are almost invariably highly stressed components it can reasonably be supposed that the behaviour of the test bars is representative of the behaviour of springs under fatigue conditions. This does not however apply to springs with material defects such as oxide penetration or a corroded surface where the initiation of a crack would be appreciably quicker and the propagation of a macrocrack would form a significant part of the total fatigue life.

5. CONCLUSION

From the results of these tests it is clear that in fatigue failure significant loss in load on a spring is unlikely to occur before failure is imminent.

6. REFERENCE

Wood, W.A. Fracture; Proceedings of Swampscott Conference, B.L. Averbach Ed. Wiley 1959.

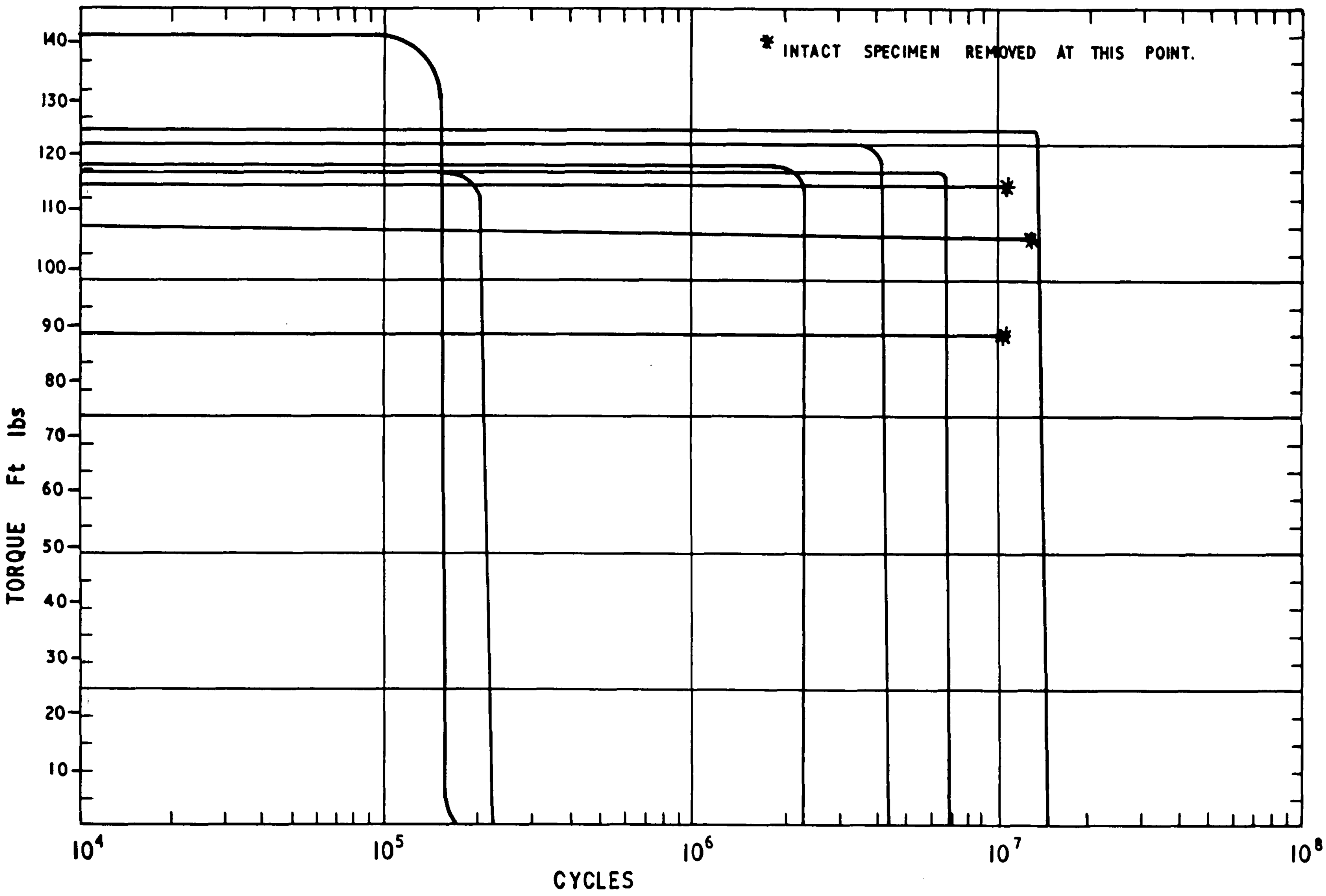

FIG. I DECREASE IN LOAD BEARING CAPACITY OF BARS RESULTING FROM CYCLIC STRESSING.