THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE EFFECTS OF OXIDE PENETRATION ON THE FATIGUE PROPERTIES OF HEAVY SPRINGS

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SUMMARY

Fatigue tests have been carried out on hot coiled helical compression springs manufactured from grade 735A50 Cr-V steel. A large degree of scatter was evident in the results obtained and metallurgical examinations of selected springs were undertaken to determine the reason for the scatter.

Springs which failed after a very small number of cycles showed extensive oxide penetration, coupled with some partial decarburisation. The structure of springs exhibiting much longer fatigue endurances was much finer and contained none of these defects.

It was concluded that the defects arose as a result of excessively high temperatures and possibly extended heating times prior to hot coiling.

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1. INTRODUCTION

As part of a long term investigation to obtain fatigue data for springs manufactured from conventional materials, fatigue tests have been carried out on hot coiled helical compression springs manufactured from 11 mm diameter ground bar, grade 735A50 (Cr-V steel).

As a result of various degrees of oxide penetration and decarburisation occurring in the springs, the results obtained are not typical for this material; nevertheless, they give a good illustration of the unpredictable fatigue behaviour of both unpeened and shot peened springs that may be caused by incorrect heating of the material before coiling.

2. MATERIAL

2.1 Composition

The actual composition of the chromium-vanadium steel used, together with the composition specified for grade 735A60 in BS 970 Part 5: 1972 are given in Table I.

2.2 Spring Design and Manufacture

The spring design used in this investigation is given in Table II. The springs were heated for coiling and oil quenched directly from the coiling mandrel. They were subsequently tempered to give a hardness of 450 to 460 HV. After end grinding and prestressing, half of the springs were shot peened to an Almen arc rise of 0.45 - 0.55 mm A2 using grade S330 shot.

3. FATIGUE TESTING

The springs were individually load tested to establish the necessary fatigue machine strokes to give the required stress ranges. All the tests were carried out on a vertical resonance fatigue testing machine, two springs being tested simultaneously. Springs were tested in both the unpeened and shot peened conditions at initial stresses of 150, 300 and 450 N/mm^2.

The results of the fatigue tests are shown in Figs. 1 to 3. In all cases there was a large amount of scatter in the results and it was found impossible to construct S/N curves from the experimental points.

4. METALLURGICAL EXAMINATION

Metallographic tests were carried out on a considerable number of springs having vastly different fatigue lives. Transverse microsections taken from the material adjacent to the fractures were examined in an attempt to elucidate the wide variations in fatigue resistance. Examples of the widely varying structures encountered are shown in Figs. 4 and 5.

Fig. 4 shows a transverse microsection of an unpeened spring which was fatigue tested through a stress range of 450 to 895 N/mm^2 and failed after only 2,700 cycles. The fracture had initiated on the inside of the coil, extensive oxide penetration being present to a depth of approximately 0.1 mm. In some places oxide penetration had resulted in the formation of cracks during fatigue testing. The structure was tempered martensite throughout, which etched lighter towards the edges indicating a carbon gradient. Some grain boundary ferrite was also present near the edges, this partial decarburisation extending to a depth of approximately 0.05 mm. The hardness in the core of this section was 459 HV 30.

Fig. 5 shows a transverse microsection taken from an unpeened spring which failed after 440,000 cycles, an endurance more than 150 times greater than the previous spring, having been tested through a stress range of 450 to 925 N/mm^2. Again the origin of the fracture was at the point of maximum stress, on the inside of the coil. This spring contained no cracks, no significant oxide penetration and no carbon gradient. The structure was again tempered martensite but was much finer than that of the previous spring (Fig. 4). The hardness in the centre of the section was 451 HV 30.

5. DISCUSSION

Figs. 1 to 3 clearly demonstrate that no relationship exists between applied stress and endurance; indeed, no real distinction can be made between unpeened and shot peened springs. The performance of the springs under test was completely unpredictable and, had such springs been placed in service, would no doubt have led to justifiable complaints regarding poor fatigue performance.

The springs in question had been produced from ground material and therefore must have been free from surface defects, decarburisation and possible oxide penetration resulting from the hot rolling process. The surface condition of the springs could only have arisen as a result of their thermal history during manufacture. All hot coiled springs, as the name implies, are subject to temperatures in excess of 850°C in atmospheres which are generally of an oxidising nature. Under such conditions of heating it is important that strict control is kept over the processing temperature, heating time and actual furnace atmosphere is oxidation and decarburisation are to be kept to a minimum. It was obvious from the various samples examined that this particular batch of springs had been subject to considerable variations in processing conditions.

A number of springs were examined metallographically but only two examples are given here to demonstrate the great variation in structure and surface condition which can occur. It is evident that the spring which failed prematurely, illustrated in Fig. 4, had suffered severe oxide penetration, along with some decarburisation probably due to an excessively high coiling temperature and, maybe, prolonged time at some temperature above 1000°C. A coarse grain structure had resulted, again a reflection of the excessive temperature employed for the purpose of coiling and hardening.

Oxide penetration of the type illustrated would certainly provide severe stress raisers under dynamic stressing conditions, which would act as points for early initiation and growth of fatigue cracks, with consequent loss of overall fatigue performance. To a lesser extent the presence of a large grain size would also aggravate early failure.

All the springs tested exhibited the specified hardness and this, together with the general appearnace of the tempered martensite structure, would seem to indicate that tempering had been carried out correctly.

As a point of interest, it can be seen from the data given in Figs. 1 and 2 that the introduction of a residual stress system at the surface by shot peening was in many cases inadequate to overcome the damage caused by oxide penetration. The application of a carbon restoration process would, of course, restore the carbon level at the surface but would not remove the damaging effects of the oxide penetration. If, however, the springs were then re-shot peened, the compressive stresses developed as has been shown in the literature(1) might be sufficient to transfer the position of maximum stress beyond the point at which the stress raising effects of oxide penetration are operative and some improvement in fatigue resistance could result. This idea is, however, dependent on the relative depth of the stress raiser and the compressive layer produced.

6. CONCLUSION

The unpredictable dynamic behaviour of hot coiled compression springs was found to be caused by oxide penetration of the surface of the springs resulting from poor heating practice prior to coiling.

7. REFERENCE

1. WATKINSON J. F. "The influence of some surface factors on the torsional fatigue strength of spring steels." Proc. Conf. on Fatigue of Metals, Inst. Mech. Eng., 1956.

TABLE I CHEMICAL COMPOSITION

	%C	%Si	%Mn	%Cr	%V	%S	%P
Actual	0.54	0.20	0.74	1.05	0.17	0.039	0.028
Specified	0.46 -0.54	0.10 -0.35	0.60 -0.90	0.80 -1.10	0.15 Min	0.040 Max	0.040 Max

TABLE II SPRING DESIGN

Bar diameter (mm)	11.18
Mean coil diameter (mm)	79.5
Total number of coils	5.9
Number of active coils	4.4
Free length after end grinding and prestressing (mm)	163
Solid stress after end grinding & prestressing (N/mm^2)	1240

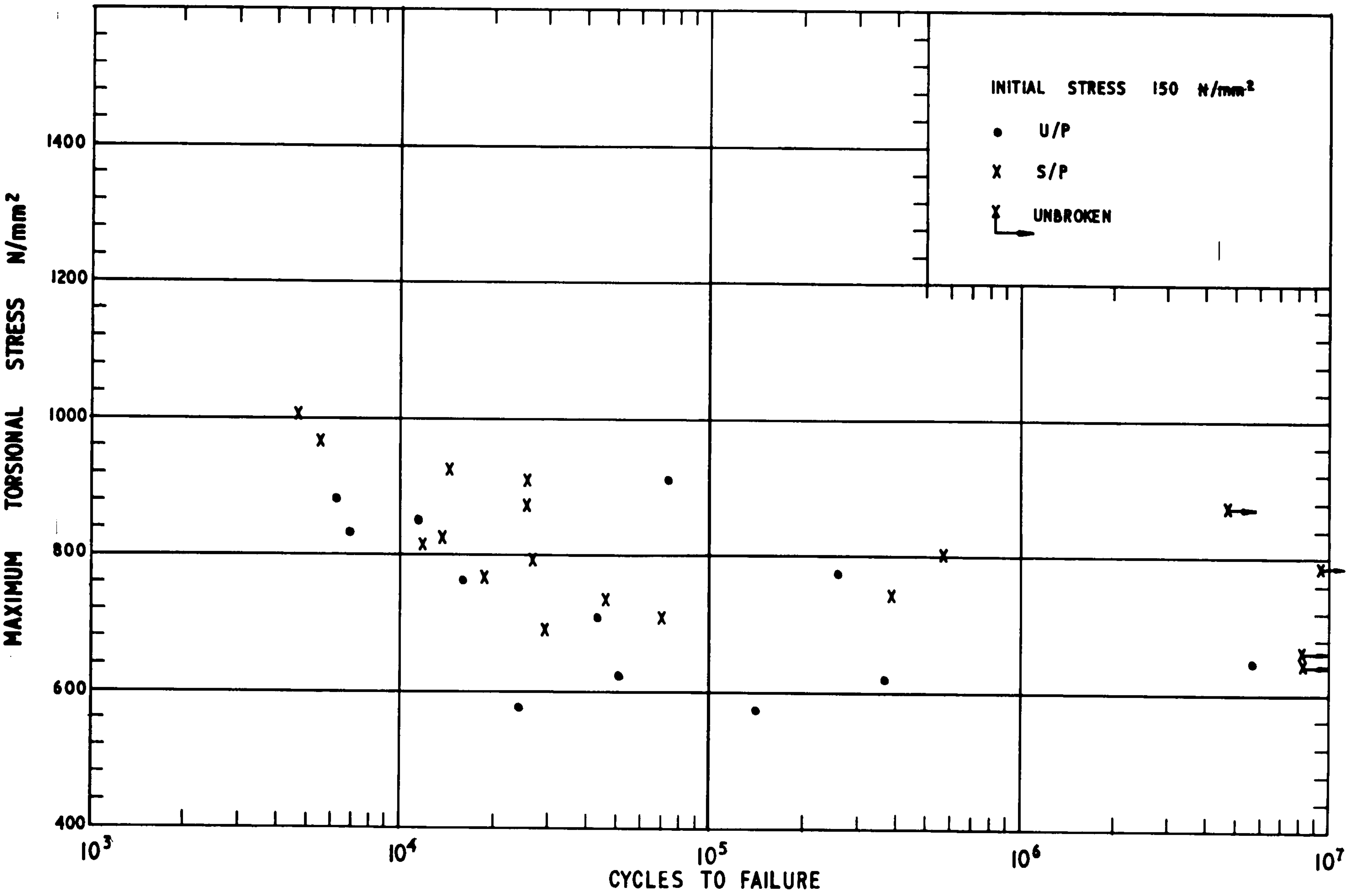

FIG. I FATIGUE DATA FOR GRADE 735A60 HOT COILED SPRINGS.

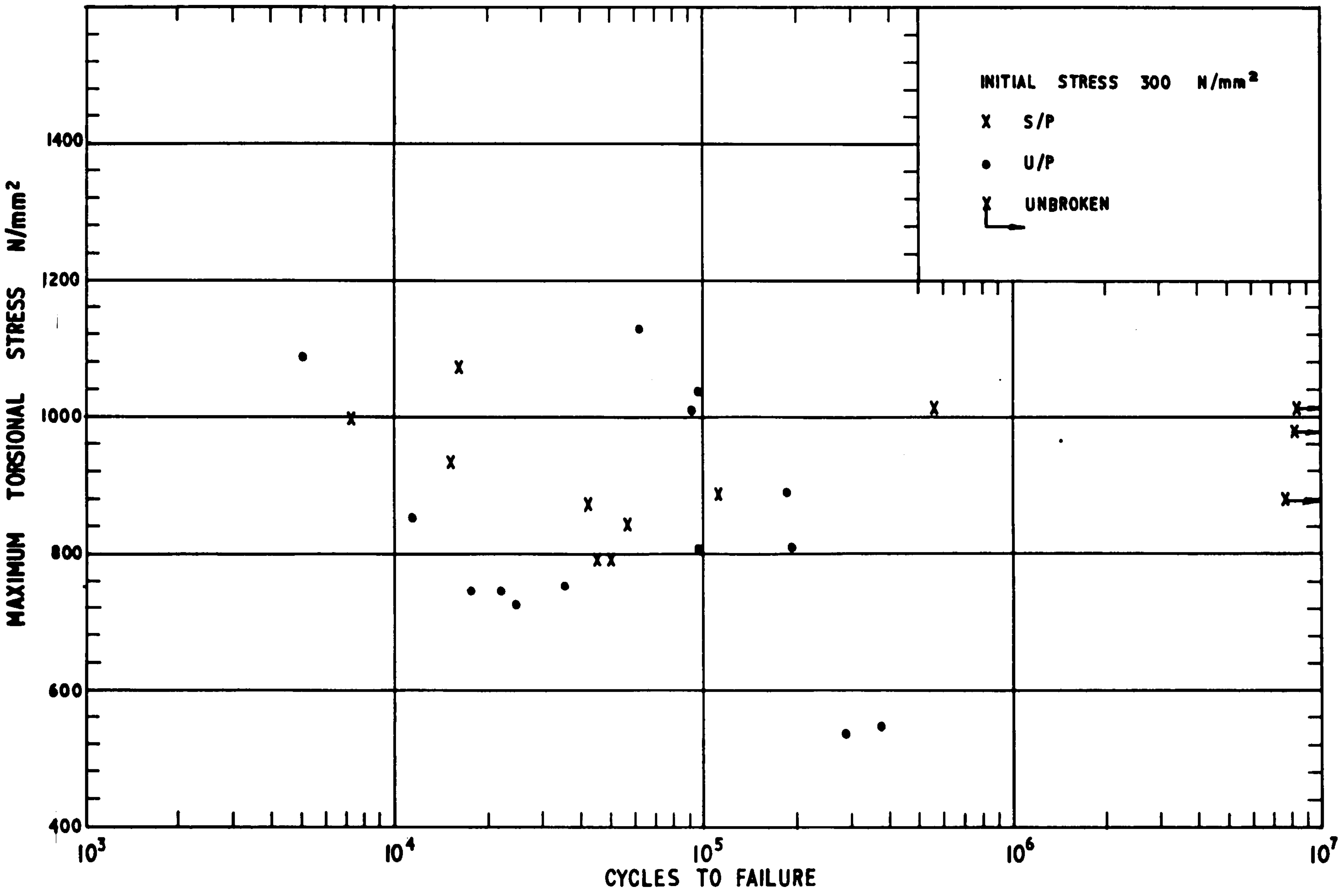

FIG. 2 FATIGUE DATA FOR GRADE 735A50 HOT COILED SPRINGS.

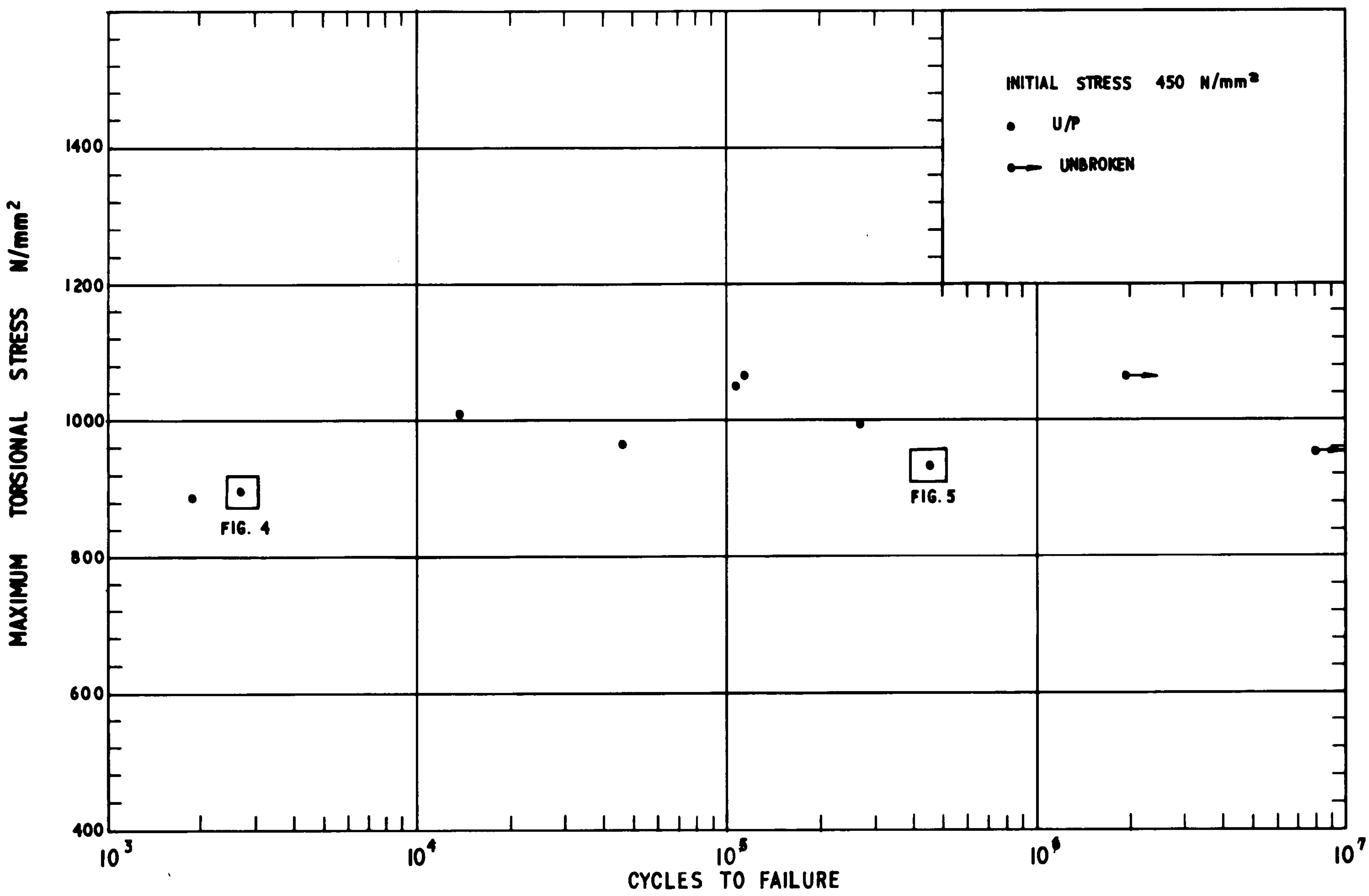

FIG. 3 FATIGUE DATA FOR GRADE 735A50 HOT COILED SPRINGS.

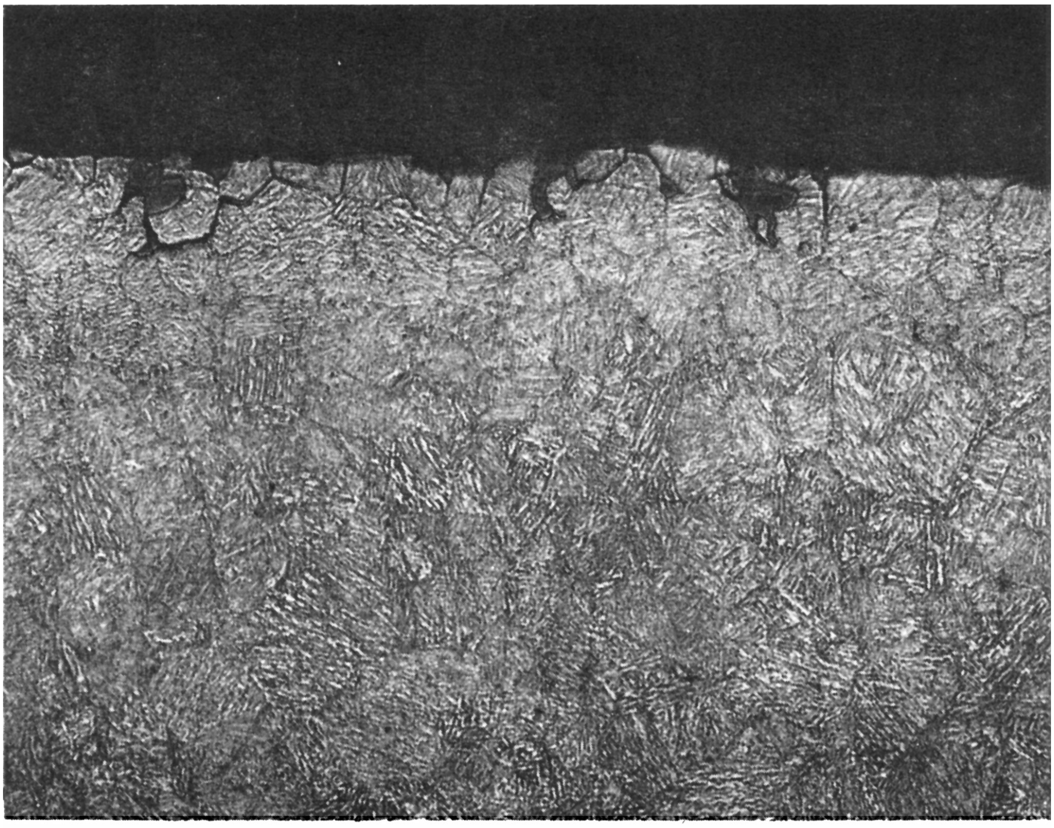

FIG.4 Transverse microsection, Spring No. 30, x 185

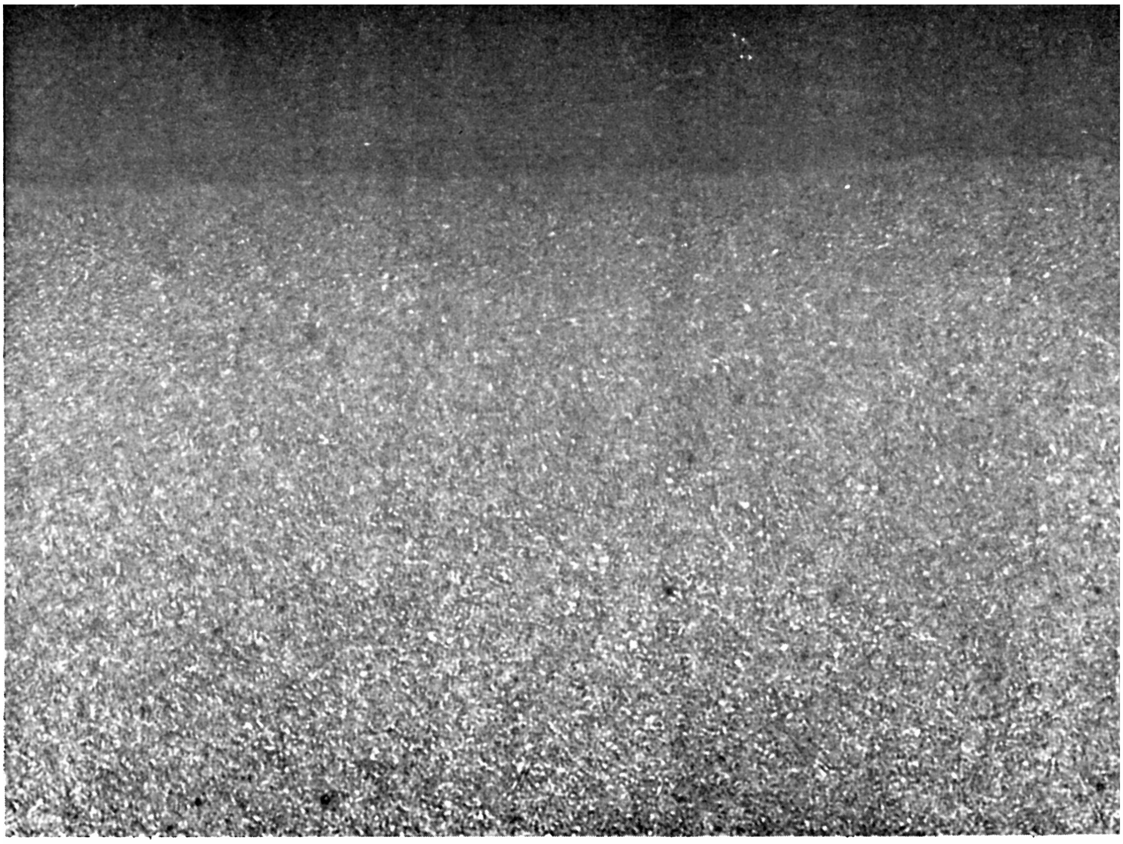

FIG.5 Transverse microsection, Spring No. 56B, x 185