THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

# THE MECHANICAL PROPERTIES OF THREE HEAVY SPRING STEELS AT TWO HARDNESS LEVELS

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## SUMMARY AND CONCLUSIONS

The hardenability, fatigue and impact properties of three grades of spring steel have been studied at two hardness levels, 520 and 620 HV. The grades investigated were silicon-manganese (250A58), carbon-chromium (527A60) and nickel-chromium-molybdenum (805A60) steels.

It was found that:-

a) the 805A60 had the greatest hardenability of the three grades, followed by the 527A60, with the 250A58 having the least.

b) the best fatigue properties at high stresses were obtained from the 620 HV materials, while at lower stresses the more normal spring hardness, 520 HV, appeared to have better fatigue resistance.

C) the 250A58 at 520 HV had the best impact resistance, probably because of its atypical fine grain size, and the 527A60 at 620 HV had the worst impact resistance.

## CONTENTS

## CONTENTS (Contd.)

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## 1. INTRODUCTION

The object of this investigation was to collect data on three heavy spring materials at two different hardness levels, 520 HV, a normal spring hardness and 620 HV. Fatigue performance, hardenability and impact properties have been investigated in order to determine the most suitable heat treatment for these materials.

## 2. MATERIALS

### 2.1 Composition

The three materials used in this investigation were 250A58 (silicon-manganese spring steel), 527A60 (carbon-chromium spring steel) and 805A60 (nickel-chromium-molybdenum spring steel). These materials were obtained in the form of as-rolled bar varying in diameter between 25 and 32 mm. The actual compositions of these steels together with those specified in BS 970: Part 5:1972 are given in Table I.

It can be seen from Table I that the chromium level in the 805A60 material is slightly lower than the minimum specified in BS 970. It was felt that, although this may have a small effect on the hardenability, the effect on other properties would be insignificant and therefore this material was considered suitable for use in this investigation.

### 2.2 Inclusion Content

Transverse and longitudinal microsections were taken of each material in the as-received condition, and examined to give an approximate determination of the inclusion level in each steel. The level was determined using a J.K. chart for 60 x 100 fields and was found to be 2 - 3 for the 250A58 bar, and less than 1 for the 527A60 and 805A60 steels. In each case the inclusions were mainly sulphides.

### 2.3 Grain Size

The prior austenite grain size in the as-received condition was determined in accordance with BS 4490:1969, by etching with hydrochloric acid/picric acid to reveal the grain boundaries. It was found to be 9 for the 250A58, 7 for the 805A60 and 6 for the 527A60.

## 3. EXPERIMENTAL PROCEDURE

### 3.1 Tempering Trials

Tempering trials were carried out using small samples of each bar in order to determine the tempering temperatures required to give hardnesses of 520 HV and 620 HV in each material. The heat treatments chosen as a result of these trials are given in Table II, and the tempering curves obtained are given in Fig. 1.

### 3.2 Hardenability Tests

The hardenability tests were carried out in accordance with BS 4437:1969, and the test method is described in detail in this standard. Two 'Jominy' test specimens were machined from each bar and each sample was then heated to a suitable austenitizing temperature, 920°C for the 250A58 material and 840°C for the other two steels, in a furnace containing small pieces of graphite to minimise decarburisation. After soaking for 30 minutes the samples were quenched at one end by a water jet using a "Metaserv" end quench unit. This apparatus has been illustrated in a previous report(1).

When the specimen had completely cooled, two parallel flats were ground, on opposite sides of the circumference, along the length of the bar to a depth of 0.4 mm. Hardness indentations were then made along these flats at regular intervals from the quenched end.

## 3.3 Tensile Tests

Four tensile test samples were taken from each bar. These were initially rough machined leaving about 0.5 mm to be removed after heat treatment. They were then hardened and tempered as outlined in Table II to give two test peices at 520 HV and two at 620 HV for each material. After tempering the samples were finally machined to a gauge diameter of 11.28 (+0.06) mm to give standard tensile test specimens conforming with BS 18: Part 2:1971.

The tensile tests were carried out on a hydraulically-powered Amsler tensile testing machine. Elongation over 50 mm was measured by means of a Baldwin extensometer.

## 3.4 Fatigue Tests

Thirty torsional fatigue specimens were rough machined from each quality. After heat treating to produce half at 520 HV and the remainder at 620 HV, they were finally ground in accordance with BS 3518: Part 4:1963, to give standard fatigue specimens with a guage diameter of 9.65 (+0.05) mm, suitable for the Schenck torsional fatigue test machine.

The fatigue specimens were then shot peened in a Tilghman Wheelabrator machine using CS 330 shot, to an intensity which would produce an Almen arc rise of approximately 0.46 mm A2.

The fatigue tests were carried out on a Schenck torsional fatigue test machine. The specimens were tested in a clockwise direction from an initial stress of zero to various maximum stresses, to give lives of up to approximately 2 x $10^6$ cycles. Each specimen was initially prestressed to the level at which it was to be tested, in order to achieve a stable test stress.

### 3.5 Impact Tests

Twelve impact test specimens, four from each bar, were rough machined and heat treated. After hardening and tempering they were machined to their final size and V-notches were cut in them to produce Charpy V-notch impact test pieces conforming to BS 131: Part 2: 1972.

Duplicate impact tests were carried out on each material at each of the two hardness levels, using a standard Charpy impact test machine.

## 4. RESULTS

### 4.1 Hardenability

The 'Jominy' curves produced from the hardenability tests are presented in Fig. 2. Each set of points is the average of two longitudinal traverses on each specimen. Table III gives the $D_I$ and $D_{HO.35}$ values for each steel for Jominy distance corresponding to 650 HV30.

### 4.2 Tensile Tests

The tensile properties of the three steels at two hardness levels are given in Table IV.

### 4.3 Fatigue Tests

The fatigue curves produced for the three materials are shown in Figs. 3 to 5 together with their 95% confidence limits. The curves are reproduced for comparison in Fig. 6.

### 4.4 Impact Tests

Table V lists the results of the Charpy impact tests for each material in each condition.

## 5. DISCUSSIONS

### 5.1 Hardenability

Table IV lists various hardenability data calculated from the curves in Fig. 1 to 3. These are the Jominy depth for a hardness of 650 HV, the 'Ideal Diameter - $D_I$, i.e. the bar diameter which could be successfully quenched in a medium which is 100% efficient, and $D_{HO.35}$ i.e. the bar diameter which could be successfully quenched in agitated oil with a heat transfer index 'H' of 0.35. These terms and the reasons for using a hardenability criterion of 650 HV are explained more fully in a previous report(1).

The 250A58 material used in this investigation had a $D_{HO.35}$ value of 17 mm which is low compared with the values of 27 to 32 mm obtained in previous work on 250A58 and 250A61(1). All the steels used previously however had a prior austenite grain size of 6 whereas the material used in this investigation had a grain size of 9. It is likely that this finer grain size contributed to the reduced hardenability of this steel because it is well established that a small grain size leads to lower hardenability(2). This is due to the fact that the grain boundary surface area increases as the grain size decreases, thus providing more sites to act as nuclei for pearlite formation.

The other factor that contributes to hardenability is the composition of the steel. Various alloying elements increase the hardenability by differing amounts. The manganese content was lower in the 250A58 material used in this investigation than in those used previously(1), and as manganese has a relatively large effect on hardenability this would have contributed to the lower hardenability of this steel.

The hardenability of the 527A60 and 805A60 steels was greater than that of the 250A58, the 805A60 having the highest hardenability of the three. This is as would be expected from the alloy content of the steels. Both the hardenability curves for the 527A60 and 805A60 materials fall within the hardenability bands given in the relevent British Standard(3), the 527A60 being near the centre of the range and the 805A60 near the lower end of the hardenability range. The 805A60 has quite a fine grain size and this coupled with its low chromium content explains why its hardenability was lower than average for this material.

One point which has come out of this work is the importance of grain size in heavy spring materials. Silicon manganese steel is used in bar diameters up to about 30 mm and problems may be experienced in hardening it at this size if the grain size is small. Although fine grain sizes are unusual they can occur, as was found in this case, and therefore it may be necessary to specify a preferred grain size, generally about 5, when ordering materials whose diameters are close to the upper limit for that steel.

## 5.2 Tensile Properties

It was not possible to obtain the tensile properties of the 527A60 material at a hardness of 620 HV as the tensile specimens broke in the grips at the point of the fillet. The corner produced there acted as a notch, raising the stress at this point and inducing premature, brittle failure.

The tensile strength and elastic properties of the three steels after tempering to a hardness of 520 HV were similar, as were those of the 250A58 and 805A60 steels at 620 HV. The ductility of 527A60 material at 520 HV as indicated by the elongation and reduction of area, was much lower than that of the other two steels.

## 5.3 Fatigue

Figures 5 to 7 show that, for each material, the effect of increasing the hardness from 520 to 620 HV is to increase the gradient of the S/N curve. The 620 HV fatigue lines for the

250A58 and 805A60 materials cross over the 520 HV fatigue curves, while the lines for the 527A60 are converging at lower stresses and may have crossed if the full S/N curve had been investigated. At high stress, therefore, increasing the hardness of all three materials from 520 to 620 HV results in an increase in fatigue life, whereas at lower stresses the 520 HV 250A58 and 805A60 materials appear to have better fatigue resistance. It appears that as the hardness is increased the gradient of the fatigue curve increases, and this implies that fatigue performance becomes less sensitive to the test stress and more sensitive to some other factor or factors. At this stage no satisfactory explanation can be given as to what these factors may be.

In Fig. 8 all the fatigue curves are reproduced for comparison and this shows that the fatigue curves for the three materials at a hardness of 520 HV are very similar. At 620 HV however the curves are quite different. The 527A60 and 250A58 curves have similar slopes but the 805A60 curve has a much steeper slope and although its fatigue resistance at high stresses is as good as the other two materials, at low stresses it is poorer than the other two materials at this hardness level.

It is generally accepted that the fatigue limit increases with hardness up to a certain level and when this hardness is exceeded it will begin to decrease. Little information is available however on the way in which limited life data varies with hardness. In a previous report(4) it was found that for shot peened 250A58 material the gradient of the S/N curve increased as the hardness was increased from 465 HV to 510 HV and from 510 HV to 540 HV. After this further work was carried out at SRAMA to try and determine the hardness at which the optimum limited life fatigue properties were obtained. Unfortunately this work was inconclusive, partly because it was carried out at only one stress level. The present investigation indicates that although increasing the hardness up to 620 HV may be beneficial for springs working at high stress levels, a more normal spring hardness may be better at low stresses.

It therefore seems unlikely that a definite hardness can be found up to which the limited life fatigue properties will improve and above which they will start to decrease, over the complete range of test stresses.

## 5.4 Impact Resistance

Table V shows that for each material the 520 HV specimens absorbed the most energy in the impact test. This is in agreement with the generally accepted view that the energy absorbed in the impact test of an alloy steel at a given test temperature increases with increasing tempering temperature.

At 520 HV the 250A58 absorbed the most energy and 527A60 the least. A similar pattern is followed at 620 HV with the 250A58 and 805A60 absorbing similar amounts of energy and the 527A60 considerably less. From the point of view of composition it would be expected that the 805A60 would have better impact properties than the 527A60 and 250A58, as both nickel and molybdenum are known to have a beneficial effect on impact properties while chromium has little effect(5). Grain size however also has a strong effect on the energy absorbed in impact tests and the high impact resistance of the 250A58 material, seen particularly at 520 HV, could well be due to the fine grain size of this material.

A previous report(6) concerned with the impact properties of various heavy spring materials, includes data for these three materials at a hardness of approximately 460 HV. In this case the 250A58 (En 45) material had by far the poorest impact resistance of the three, with only 5 joules absorbed in fracture. It did however have a more typical grain size value, 6, than the material used in this investigation. The 527A60 and 805A60 material had values of approximately 13 and 20 joules absorbed in fracture and these figures can be accounted for partly by the lower hardness used but mainly by the fact that the grain sizes of the two materials were 11 and 9 respectively. It is important to realise therefore that for any given steel grade impact resistance will vary with grain size, hardness and the actual compositions of the steel.

The fractures of the test specimen were examined and, as would be expected from the results the 527A60 (620 HV) fractures have a granular appearance and the 250A58 (520 HV) fractures have the most fibrous appearance, while the other specimens have fractures whose appearance are intermediate between the two extremes.

## 6. CONCLUSIONS

1. The 805A60 material had the highest hardenability of the three grades of steel and the 250A58 the lowest. Due to the fine grain size of the 250A58 material, the hardenability was lower than would be expected for this steel grade.

2. The best fatigue properties at high stresses were obtained from the 620 HV materials, while at lower stresses the more normal spring hardness, 520 HV, appeared to have better fatigue resistance.

3. Of the three steels investigated, the 250A58 material at a hardness of 520 HV had the highest impact strength, probably because of its fine grain size. The 527A60 at a hardness of 620 HV had the lowest impact strength.

## 7. REFERENCES

1. Gray, P., 'Hardenability of Silicon-Manganese Spring steel (250A58 and 250A61)', SRAMA Report No. 280, July 1977.
2. Thelning, K.E., 'Steel and its Heat Treatment' Butterworths, 1967.
3. B.S.970: Part 5: 1972 "Carbon and Alloy Spring Steels for the Manufacture of Hot Formed Springs".
4. Haynes, R., 'The effect of Shot Peening on the Fatigue Behaviour of Silicon-Manganese Spring Steel', SMRA Report No. 161, September 1966.

5. Dieter, G.E., 'Mechanical Metallurgy' McGraw-Hill, 1961.
6. Owen, A.P., 'The Impact Transition Properties of Spring Materials', SRA Report 199, April 1972.

## TABLE I CHEMICAL COMPOSITION OF STEELS USED IN THIS INVESTIGATION

| MATERIAL | | %C | %Si | %Mn | %Cr | %Ni | %Mo | %S | %P |
|---|---|---|---|---|---|---|---|---|---|
| 250A58 | ACTUAL | 0.56 | 1.83 | 0.77 | | | | 0.023 | 0.017 |
| | SPECIFICATION | 0.55-0.62 | 1.70-2.10 | 0.70-1.00 | | | | 0.050 max. | 0.050 max. |
| 527A60 | ACTUAL | 0.59 | 0.21 | 0.77 | 0.78 | | | 0.039 | 0.018 |
| | SPECIFICATION | 0.55-0.65 | 0.10-0.35 | 0.70--1.00 | 0.60-0.90 | | | 0.040 max. | 0.040 max. |
| 805A60 | ACTUAL | 0.59 | 0.24 | 0.81 | 0.30 | 0.60 | 0.19 | 0.023 | 0.015 |
| | SPECIFICATION | 0.55-0.65 | 0.10-0.35 | 0.70-1.00 | 0.40-0.60 | 0.40-0.70 | 0.15-0.25 | 0.040 max. | 0.040 max. |

## TABLE II HEAT TREATMENT

| MATERIAL | HARDNESS (HV 30) | HEAT TREATMENT |
|---|---|---|
| 250A58 | 520 | O.Q 920°C, Temper 1 hr 430°C |
| | 620 | O.Q 920°C, Temper 1 hr 390°C |
| 527A60 | 520 | O.Q 840°C, Temper 1 hr 390°C |
| | 620 | O.Q 840°C, Temper 1 hr 300°C |
| 805A60 | 520 | O.Q 840°C, Temper 1 hr 380°C |
| | 620 | O.Q 840°C, Temper 1 hr 290°C |

## TABLE III HARDENABILITY DATA

| MATERIAL | JOMINY DEPTH FOR 650 HV (mm) | $D_{H0.35}$ (mm) | DI (mm) |
|---|---|---|---|
| 250A58 | 7.0 | 17 | 50 |
| 527A60 | 17.0 | 46 | 90 |
| 805A60 | 19.7 | 53 | 98 |

## TABLE IV TENSILE PROPERTIES OF THE THREE STEELS AFTER HARDENING AND TEMPERING TO HARDNESSES OF 520 & 620 HV

| MATERIAL | HARDNESS HV 30 | $R_M$ N/mm$^2$ | $R_{p0.05}$ N/mm$^2$ | $R_{p0.1}$ N/mm$^2$ | L of P N/mm$^2$ | Z (R of A) % | A (E l) % |
|---|---|---|---|---|---|---|---|
| 250A58 | 520 | 1680 | 1510 | 1525 | 1335 | 38.5 | 11.7 |
| | 620 | 1990 | 1790 | 1820 | 1530 | 26.9 | 5.5 |
| 527A60 | 520 | 1695 | 1445 | 1470 | 1345 | 5.1 | 7.5 |
| | 620 | | | | | | |
| 805A60 | 520 | 1755 | 1560 | 1570 | 1435 | 34.0 | 10.2 |
| | 620 | 2070 | 1750 | 1770 | 1575 | 18.0 | 5.5 |

TABLE V RESULTS OF CHARPY V-NOTCH IMPACT TESTS CARRIED OUT AT 17°C

| MATERIAL | HARDNESS HV 30 | ENERGY ABSORBED IN FRACTURE (joules) |
|---|---|---|
| 250A58 | 520 | 12<br>15 |
| | 620 | 7<br>7 |
| 527A60 | 520 | 4<br>8 |
| | 620 | 4<br>4 |
| 805A60 | 520 | 8<br>9 |
| | 620 | 7<br>8 |

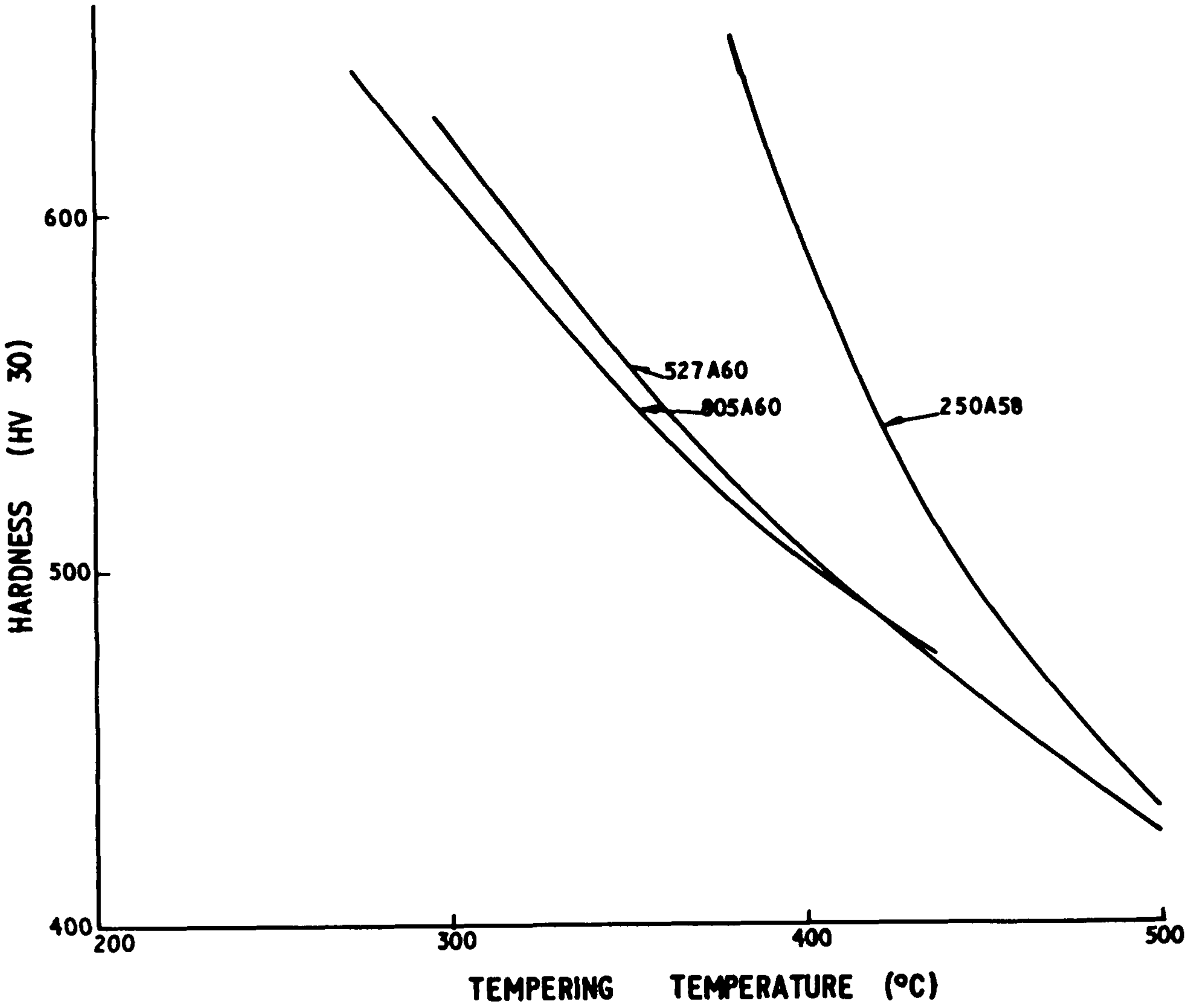

FIG. I. TEMPERING CURVES FOR 250A58, 527A60 AND 805A60 SPRING STEELS.

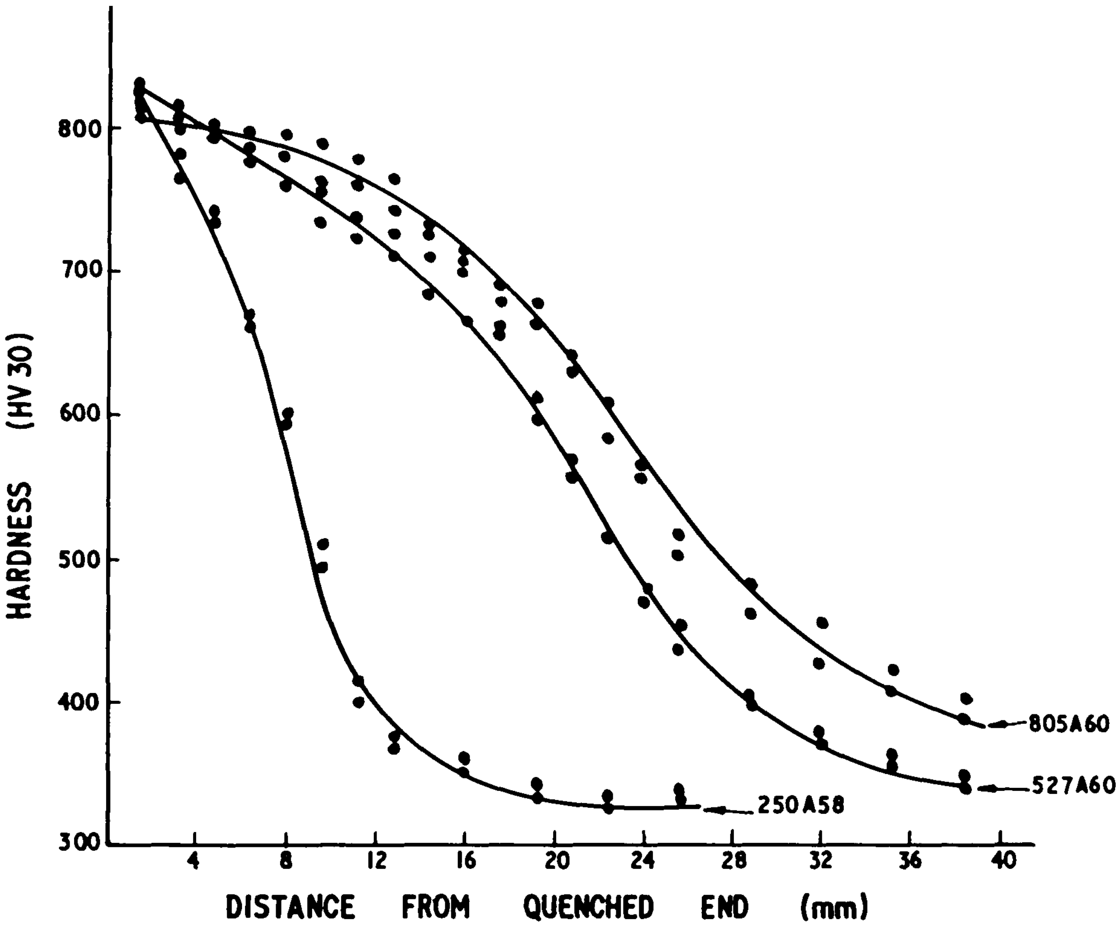

FIG. 2 JOMINY END QUENCH CURVES FOR 250A58, 527A60 AND 805A60 SPRING STEELS.

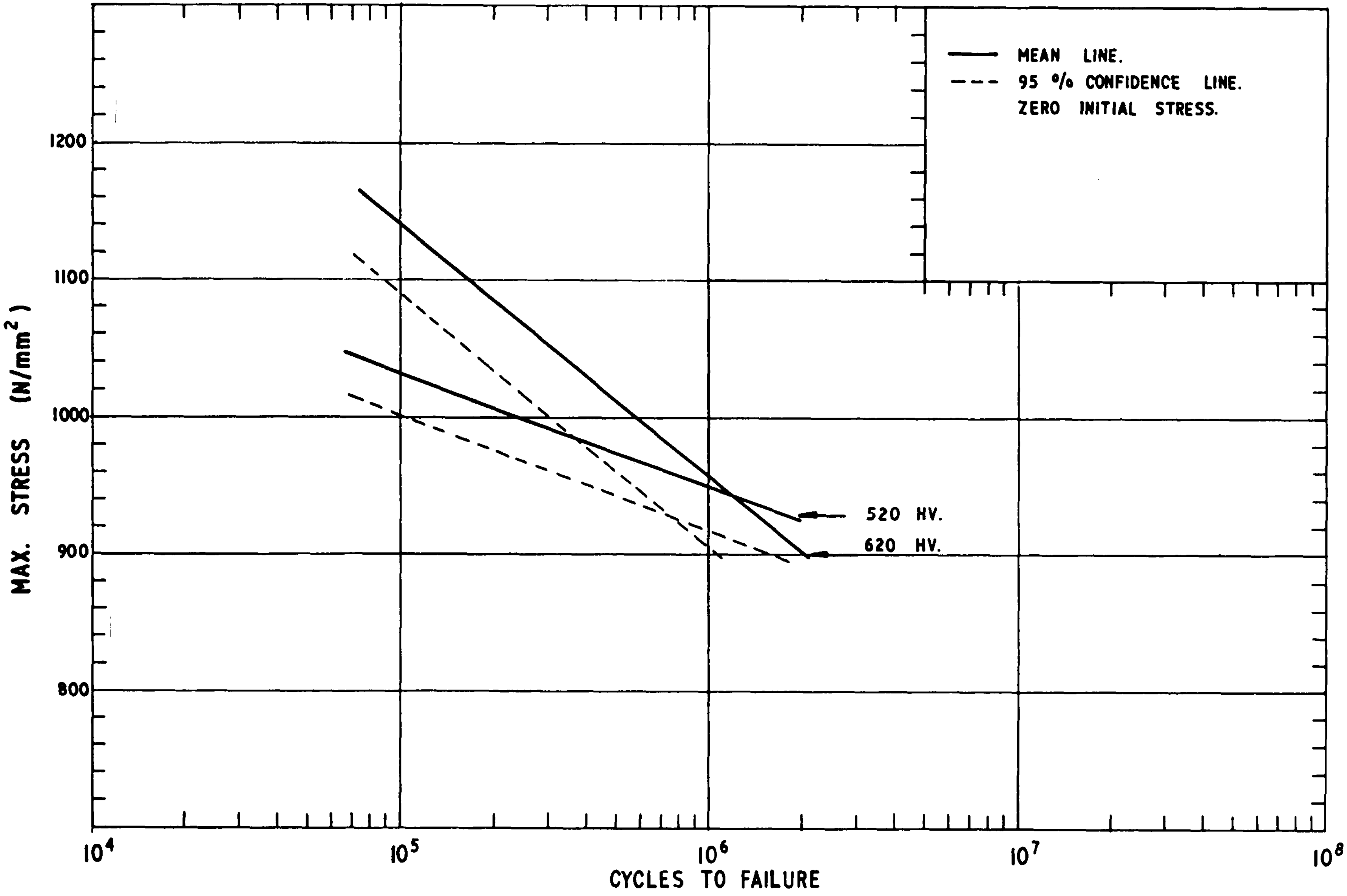

FIG. 3 FATIGUE CURVES FOR SHOT PEENED 250A58 TORSION BARS AT TWO HARDNESS LEVELS.

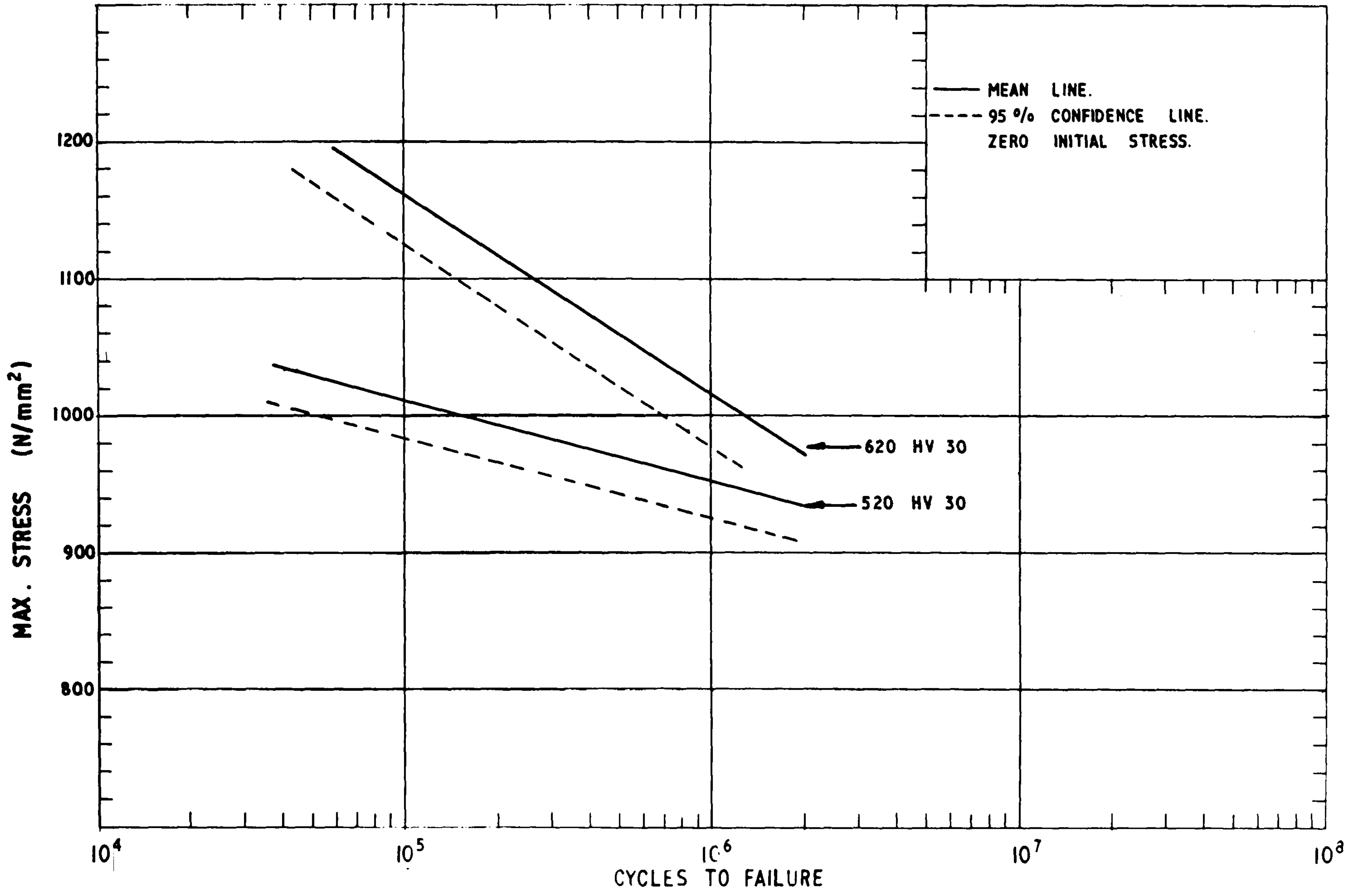

FIG. 4 FATIGUE CURVES FOR SHOT PEENED 527A60 TORSION BARS AT TWO HARDNESS LEVELS.

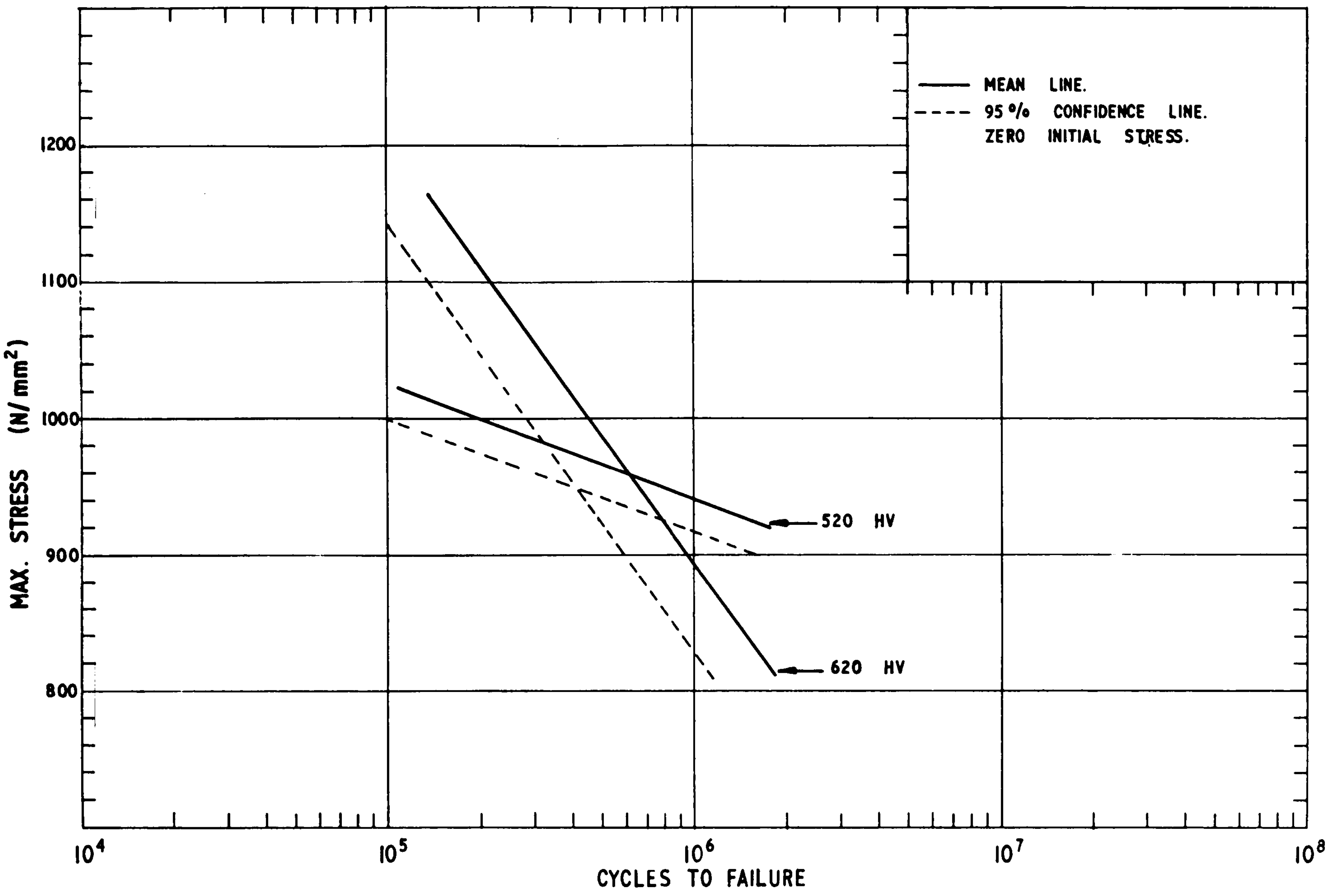

FIG. 5. FATIGUE CURVES FOR SHOT PEENED 805A60 TORSION BARS AT TWO HARDNESS LEVELS.

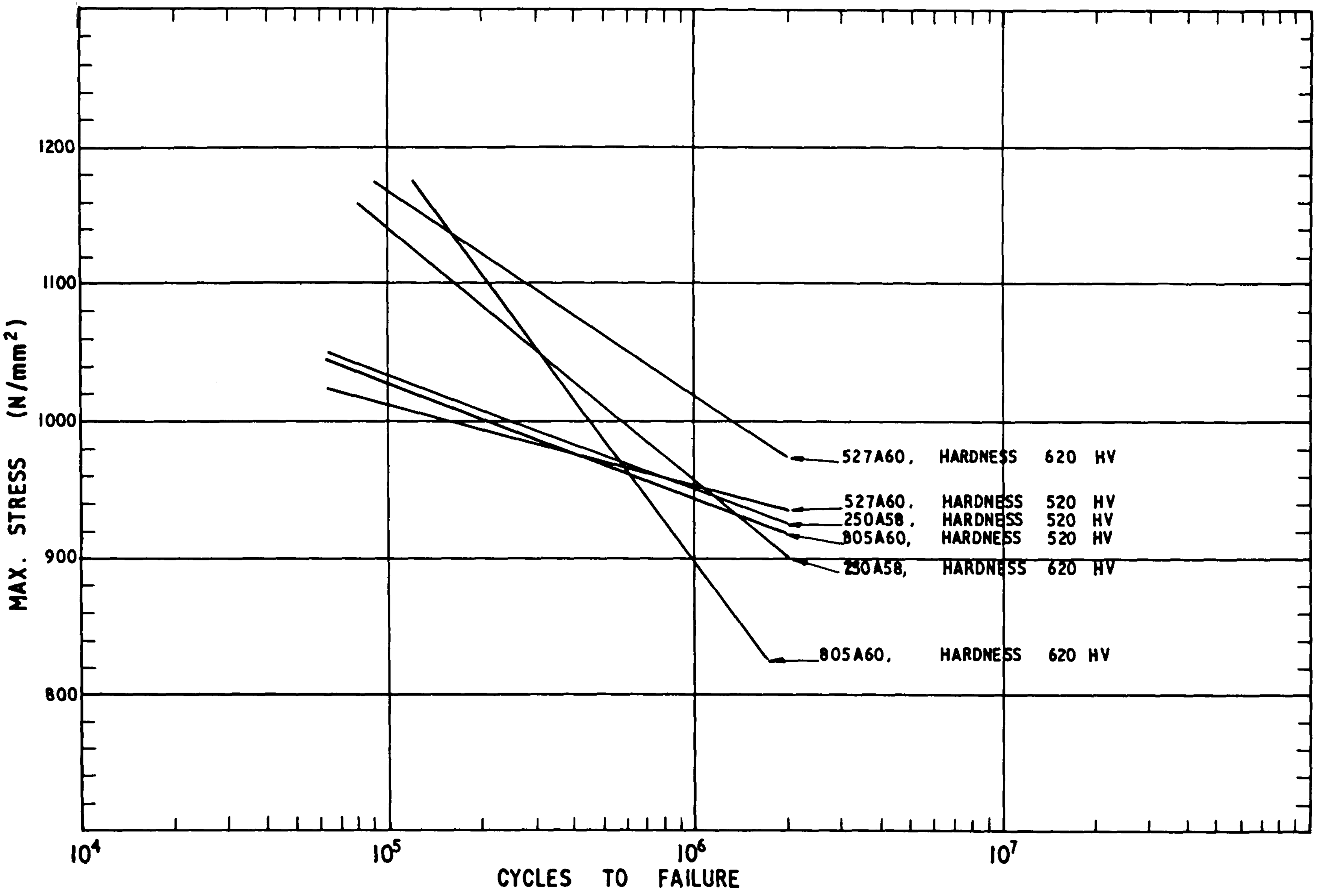

FIG. 6 FATIGUE CURVES FROM FIGS. 5-7 FOR COMPARISON.