THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

AN INVESTIGATION INTO THE EFFECT OF BAR SURFACE PREPARATION ON THE FATIGUE PROPERTIES OF MEDIUM HELICAL SPRINGS MANUFACTURED FROM En45A BAR

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SUMMARY

Fatigue tests have been carried out on springs manufactured from black bar and also springs manufactured from bars with two prepared surfaces, which were a centreless ground surface and a centreless turned ' peeled' surface. While the tests clearly showed that the springs manufactured from bars with a prepared surface had longer fatigue lives than springs manufactured from as rolled bar, no distinction could be made between the different types of prepared surface. It is thought that this is because the springmaking process introduced faults in the springs which were the limiting factor in the fatigue lives of the prepared bar springs.

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1. INTRODUCTION

The cheapest available bar material for medium and heavy spring manufacture is the product known as black bar, this is essentially hot rolled bar in the as rolled condition, it may have merely been allowed to air cool after rolling in which case it would be in the normalised condition, or it may have been annealed to make it easier to coil. In this condition the bar surface is far from ideal for the manufacture of springs for dynamic applications. The surface finish will be rough and scaled, there will invariably be some decarburised material at the surface and possibly also laps, seams or oxide penetration. These defects frequently cause problems in dynamic service and if severe can cause difficulty in heat treatment, by causing quench cracks for example.

As hot rolling is used in all steel plant to reduce material from the cast section to either final or some intermediate size, it must be accepted that all steel leaving the rolling mill will have some degree of surface imperfection.

In the spring industry, when a high quality product is required the normal solution to the problem of poor surface quality on rolled bar has been to centreless grind black bar to remove sufficient material from the bar surface to provide a sound surface on the bar. In recent years centreless turning has been developed as an alternative method of removing the as rolled surface of the bar to provide a high quality surface for springmaking. A number of variants of this process have been developed, these are known by a variety of names such as auto-finish and peeled bar, all these processes have a cost advantage over centreless grinding and there is a further marginal gain in that the swarf produced is suitable for sale as scrap which is not the case with grinding. The more recent versions of this process can produce material with an almost polished surface finish which has a better appearance than ground bar.

In order to assess the suitability of material with the cheaper centreless turned finish for use in spring manufacture, comparative tests have been made with helical compression springs manufactured from this material, black bar and centreless ground bar using approximately 12 mm bar dia. material.

2. MATERIAL AND SPRING MANUFACTURE

The material for this work was purchased as a single consignment of En 45A black bar from a stockholder. The bar was then processed into springs by three separate routes as follows.

Black Bar Springs

After samples had been removed for examination the bars were sent to a member firm where they were cold coiled to the design given in Table I on a Bennett Maxicoil II coiling machine. The springs were then forwarded to a second member firm where they were hardened and tempered to a hardness of 520 HV20 and end ground.

Centreless Turned Bar Springs

Black bar material was fully annealed and examined to determine the maximum defect depth in the annealed material. The bar stock was then sent to a specialist bar turner where the centreless turning (peeling) operation was carried out removing 2 mm from the bar diameter. Samples were taken before the material was sent for coiling and heat treatment by the same route as the black bar springs. The hardness of the springs was measured as 520 HV20.

Centreless Ground Bar Springs

Black bar material was examined to determine the extent to which the material was affected by decarburisation, the material was then sent for reeling and centreless grinding and subsequently for coiling. Unfortunately the material in this condition proved difficult to coil and it was necessary to anneal the material. Tube annealing failed to prevent decarburisation of the surface, therefore a further 0.70 mm was removed from the surface to eliminate the affected material before the springs were coiled. The springs were then coiled from the bar and heat treated in the same manner as the first two batches to a measured hardness of 515 HV20.

3. EXPERIMENTAL PROCEDURE

3.1 Fatigue Testing

The springs were prestressed solid five times then load tested on the Association's 30 ton vertical load testing machine to determine the lengths corresponding to the maximum and minimum stresses required. Springs were fatigue tested in either a vertical resonant frequency or a horizontal forced motion machine, depending on the required stroke. In general, springs tested over the stress range 100 - 600 N/mm^2 were tested on the resonant frequency machine and the higher stress ranges were tested on the forced motion machine.

After failure each broken spring was examined to establish the origin of failure, where necessary metallographic work was undertaken to supplement the visual examination.

3.2 Metallographic Examination

Sections taken at random from finished springs showed that after heat treatment both the peeled bar and ground bar were free both from decarburisation as measured by the presence of free ferrite and other surface defects. The black bar springs had 0.13 mm of partial decarburisation at the surface but did not suffer oxide penetration or other surface defects.

3.3 Surface Roughness Measurements

Measuements of the surface roughness of the three materials were made with a linear talysurf with a vertical magnification of 1,000 x and a horizontal magnification of 20 x. The results of these measurements can be seen in Fig. 1 and Table 2.

4. DISCUSSION AND RESULTS

The results of the fatigue tests are shown in Table IV - VII. Although the mean lives of the peeled bar springs appear to be slightly lower than those of the ground bar springs this difference is not statistically significant at any stress level and could have occurred by chance. At the 900 N/mm^2 level there is a significant difference at the 99% level between the black bar and either of the prepared bars. At the 600 N/mm^2 level no significant difference can be detected due to the larger spread of results as the fatigue limit is approached.

The examination of the failed springs proved most interesting, examination of the black bar springs showed that out of 30 springs two had not been broken during testing, six had failed at quench cracks, four had originated at the end coil, two had origins in the outside of the coil, three had broken at the coil- coil adjacent position and the remaining thirteen had failed at the inside of an active coil. It is not difficult to interpret this pattern of results as being due to fatigue initiating at the point in the bar surface where the greatest stress concentration occurs in the bar surface.

When the springs manufactured from peeled bar were examined, however, no less than half the failures had originated from the outside of the coil and appeared to be associated with a mark on the bar surface made during coiling, while only six of the springs had failed from the inside of the coil. This pattern was repeated with the ground bar springs with over half of these failing from coiling marks and a further six failing from the end coil.

While it is possible to interpret the results of the springs manufactured from black bar as being due to the defects on the bar surface with the bias towards failure on the inside of the coil being due to the higher stresses imposed on this part of the coil. In case of springs coiled from the prepared bars it is clear that manufacturing defects are the limiting factor in determining the life of the spring and the exact form of surface preparation does not significantly affect the fatigue life.

The examination of the fatigue failures therefore supports the results obtained by statistical analysis of the fatigue lives, since if the springs are failing from the same faults as coiling marks and end coils, then a change in the surface preparation of the bar is unlikely to affect the fatigue life. In the case of springs manufactured from black bar the surface finish of the bar is the limiting factor in the fatigue life of the spring and this is reflected in the results. It should be emphasised that the coiling marks on these springs were not severe, therefore it seems likely that further improvements in the fatigue life of springs are likely to be obtained by attention to the springmaking process rather than the material surface. Under these circumstances there is no technical merit in preferring either peeled or ground bar for a given application and the decision will be goverened by commercial factors such as cost and availability.

5. CONCLUSIONS

1. The fatigue lives of springs manufactured from black bar was inferior to that of springs manufactured from prepared bars.

2. No significant difference was found between the fatigue lives of springs manufactured from ground bar and springs manufactured from peeled bar.

3. The limiting factors in the life of springs manufactured from prepared bars were defects introduced during spring manufacture.

TABLE I SPRING DESIGN

	Black Bar	Peeled Bar	Ground Bar
Bar diameter mm	14.6	12.7	12.0
Mean coil diameter mm	120	120	120
Total coils	6.25	6.25	6.25
Active coils	4.25	4.25	4.25
Hardness HV	520	520	515

TABLE II TALYSURF MEASUREMENTS

	Black Bar	Peeled Bar	Ground Bar
Horizontal magnification	20	20	20
Vertical magnification	1,000	1,000	1,000
CLA μ_M	3.2	0.2	1.9

TABLE III CHEMICAL COMPOSITION OF BAR

Carbon	Silicon	Manganese	Sulphur	Phosphorus
0.68%	1.97%	0.92%	0.034%	0.015%

TABLE IV FATIGUE RESULTS STRESS RANGE 100-600 N/mm^2
(Cycles to Failure)

Black Bar	Peeled Bar	Ground Bar
226,710	145,500	305,600
207,200	369,260	281,600
77,700	536,500	451,200
48,100	125,060	494,700
51,800	64,750	200,400
		239,400
2 unbroken at 10^6 cycles	2 unbroken at 10^6 cycles	3 unbroken at 10^6 cycles

TABLE V FATIGUE RESULTS STRESS RANGE 100-900 N/mm^2
(Cycles to Failure)

Black Bar	Peeled Bar	Ground Bar
20,350	44,400	42,550
25,900	33,300	55,500
35,890	61,790	46,250
23,310	34,410	51,800
31,450	39,960	62,900
30,710	44,400	66,600
29,600	40,700	53,650
43,290		55,500

TABLE VI FATIGUE RESULTS STRESS RANGE 100-1000 N/mm^2
(Cycles to Failure)

Peeled Bar Springs	Ground Bar Springs
30,700	42,850
31,450	42,550
19,240	40,700
40,700	44,400
29,600	37,000
37,000	22,200
25,900	33,300

TABLE VII FATIGUE RESULTS STRESS RANGE 100-1100 N/mm^2
(Cycles to Failure)

Black Bar Springs
29,600
10,360
18,500
20,300
22,200
14,800
22,200

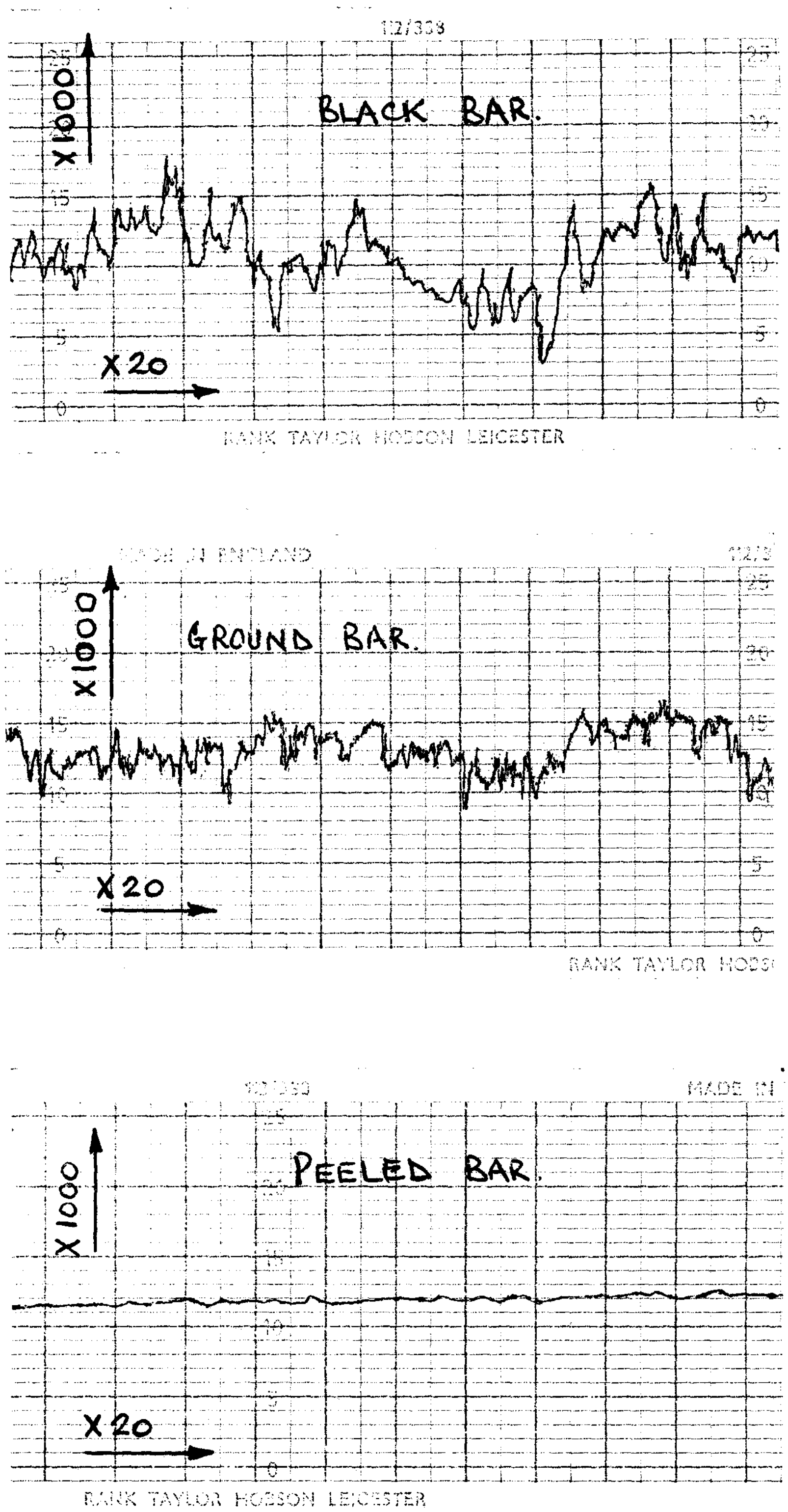

FIG. 1 TALYSURF TRACES OF THREE BAR SURFACES