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Co-inventors of the polishing-peening method for strengthening springs, James H. Maker (left) and George W. Kurasz, inspect a rack of springs taken from an electropolishing tank.

GETTING HIGHER STRESS CAPACITY in LONG-LIFE SPRINGS

By GEORGE W. KURASZ and JAMES H. MAKER

Electropolishing to remove or minimize surface defects followed by shotpeening to induce compressive stresses in surface layers raise fatigue strengths of steel springs appreciably. Such springs are designed for demanding applications — valve springs in racing cars, for example.

Employing a method involving electropolishing followed by shotpeening, we have raised fatigue strengths in automotive valve springs to exceptional levels. Briefly, the electropolishing virtually eliminates all small surface defects and minimizes the effects of larger defects by removing a measured depth of metal. Shotpeening then induces compressive stresses in these surfaces. The process is covered by our patent (U. S. 3,516,874).

We have processed springs wound of ASTM A230 to give a fatigue life of over 25 million cycles at a maximum stress of 155,000 psi. During the research, we worked with high-quality springs of two common spring steels: ASTM A228 (0.70 to 1.00 C, 0.20 to 0.60 Mn, 0.12 to 0.30 Si) and ASTM A230 (0.60 to 0.75 C, 0.60 to 0.90 Mn, and 0.15 to 0.30 Si). Laboratory tests on more than 250 springs have convinced us that electropolished, shotpeened springs are ready for field testing. In fact, this program is underway, and early results are quite encouraging.

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How the Process Was Developed

Helical springs are, of course, coiled from wire. Because the surface of the rolled and drawn wire constitutes the surface of the spring,

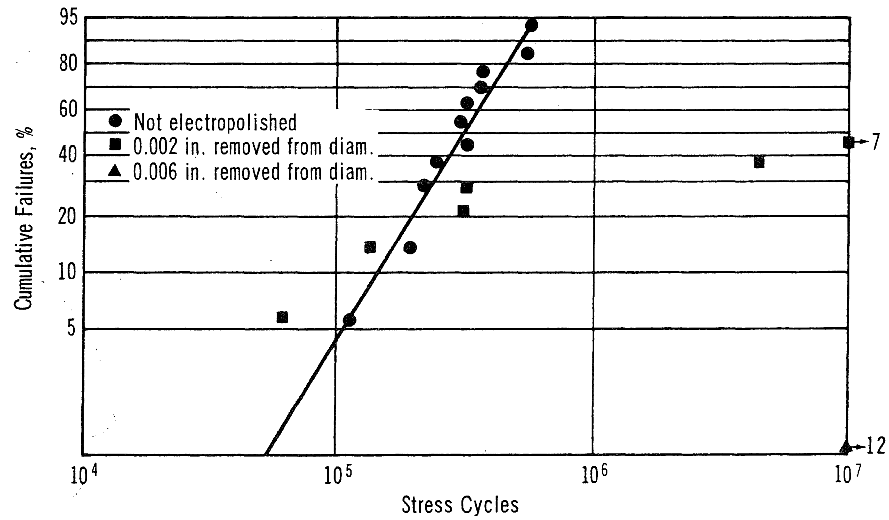

Fig. 1 — Electropolishing improves the fatigue life of springs by removing surface defects which can initiate cracks. Since the 12 springs which were polished to 0.006 in. outlasted the 10^7 cycle limit, the degree of improvement apparently varies with the depth of polishing. Maximum stress: 110,000 psi. Figures 1, 2, and 3 are Weibull probability diagrams of data on springs of ASTM A230 wire, 0.156 in. diameter, 0.125 stress ratio.

any processing defects will be situated on surfaces, regions of highest applied stress. Though helical springs can be made of wire which has been centerless ground, defects may be introduced later when the springs are formed.

Thus, we began this work to investigate the effect of removing or minimizing all defects before peening. Since electropolishing seemed the easiest way to reduce the stress concentrations, we employed that method from the start.

For specimens, we used a large number of shotpeened valve springs which had been thoroughly tested for endurance limit (which was found to be 120,000 psi at a 0.125 stress ratio – ratio of minimum to maximum stress). Polishing removed about 0.004 in. of metal from the wire diameter. When the polished springs were then repeened, stress relieved, and tested as before, we found that the fatigue limit had risen to at least 150,000 psi. More extensive tests were then planned to determine the limits of the technique.

To represent most fatigue-resisting spring materials, we chose valve-spring wire and music wire – the first is heat treated, while the other is cold drawn to strength. All springs were designed so that they could be tested at very high levels of stress.

In the first phase, we used valve-spring wire of ASTM A230 to investigate the effects of different depths of surface removal by electropolishing. The conditions tested are summarized as follows:

Condition	Springs Tested
As-formed	12
As-formed and polished (0.002 in. removed)	12
As-formed and polished (0.006 in. removed)	12
As-formed and peened (cast shot, S170 size)	36
As-formed, peened, polished (0.002 in. removed)	24
As-formed, peened, polished (0.006 in. removed)	24
As-formed, polished, peened (0.006 in. removed)	12

The springs were electropolished in a laboratory tank, and tested on a Krouse fatigue test machine at 1,800 rpm in a sinusoidal mode. (All springs had been previously oiled to protect them against humidity.)

The second phase involved springs of music wire (ASTM A228; 0.70 to 1.00 C, 0.20 to 0.60 Mn, 0.025 P max, 0.030 S max, 0.12 to 0.36 Si). Most of the springs were polished as before, but some were made from prepolished wire. Tests were as follows:

Condition	Springs Tested
As-formed and peened	32
As-formed, polished (0.004 in. removed), peened (cast shot, S70 size)	80
As-polished wire (0.004 in. removed), formed, peened	21

We ran these tests at increasing stresses until we could determine fatigue limits for each condition. More than 250 springs were tested, giving us enough data to verify conclusions.

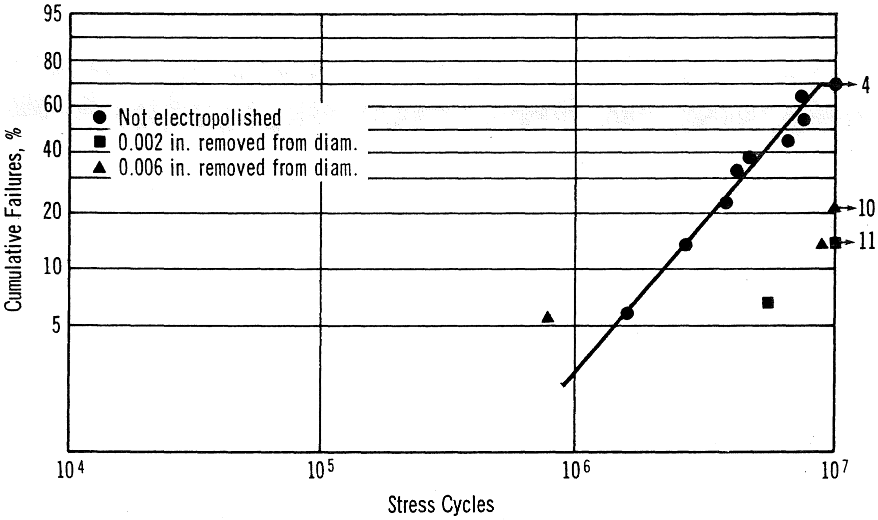

Fig. 2 — Electropolishing raised the fatigue lives of springs which had been shotpeened, again demonstrating the benefits of surface removal. Shotpeening itself improved fatigue lives even though the maximum stress was 155,000 psi (compare with Fig. 1).

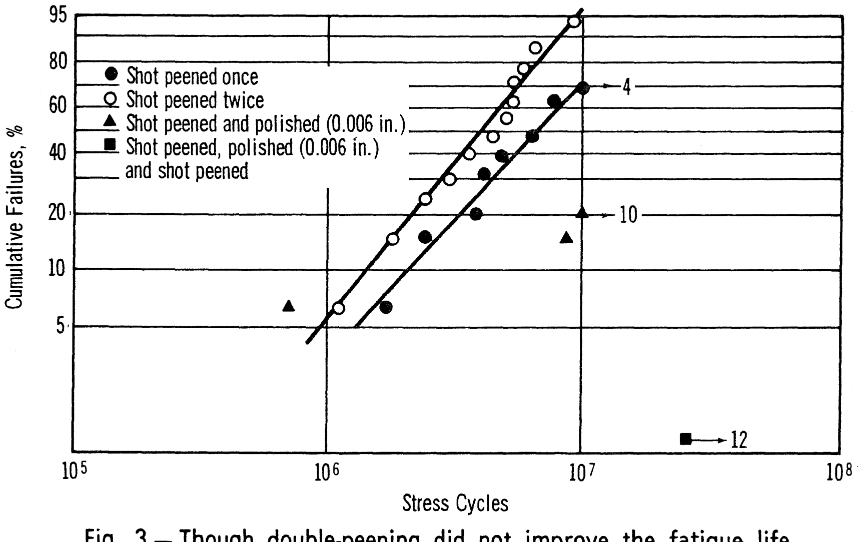

Fig. 3 — Though double-peening did not improve the fatigue life of springs, a combination of peening, polishing, and further peening raised their endurance appreciably. Note that all 12 of the springs receiving the combination treatment withstood cycling at the maximum stress (155,000 psi) for more than 25 million cycles.

Effects of Electropolishing

In Fig. 1, 2, and 3, data are presented as Weibull probability plots. Ordinates indicate cumulative failure percentages, and abscissas, the number of cycles to failure. The straight line of Fig. 1 reveals that as-formed springs experienced successive failures at 110,000 psi, the maximum stress. Removing 0.002 in. from the diameter by electropolishing raised median life, but not the life to early failure. Apparently, this amount of polishing was not enough to eliminate or minimize stress raisers adequately. When we polished away 0.006 in. of the diameter, however, the 12 springs remained intact when tested beyond the 10^7 cycle limit, the normal fatigue testing range for shot-peened valve springs.

Figure 2 shows the same sequence for springs which had been shot-peened before being polished. Note that the maximum stress has been increased to 155,000 psi. At these stresses, minor relaxation occurs, and the final stresses are slightly lower. All but two of the springs which were polished to remove 0.006 in. from the wire diameter lasted beyond the 10^7 cycle limit, and one of the failures was caused by a subsurface inclusion.

When another series of the springs discussed above was tested at a maximum stress of 160,000 psi, five of the 12 peened springs with 0.002 in. removed failed, as did two of the springs with 0.006 in. removed. Clearly, the fatigue limit was exceeded.

Figure 3 shows further comparisons at the 155,000 psi stress level. The two lines show that double-peening with the same size of shot may be slightly detrimental, but results are consistent. For comparison, we have added points from Fig. 2 for springs with 0.006 in. removed.

A set of 12 springs which were repeened after polishing lasted for 25 million cycles, indicating that repeening after polishing constitutes the optimum practice. Apparently, the compressively stressed layer is deep enough to minimize the effects of subsurface inclusions, as well as providing maximum compression in the surface layer.

Tests With Music Wire

Turning to the second phase of the work, we should note that 21 of the 32 springs of music wire lasted beyond the 10^7 cycle limit at the two maximum stresses (140,000 and 150,000 psi), proving that the music wire was of high quality. Then, electropolishing 0.004 in. from the diameter before shotpeening raised the fatigue limit for 10 million cycles to between 167,000 and 180,000 psi.

In fact, only one of the 80 polished, peened springs failed, and that was at the highest stress, 180,000 psi. (Five sets of 16 springs each were tested at the following levels: 145,000, 150,000, 160,000, 167,000, and 180,000 psi.)

From Laboratory to Production

At this plant, pilot production of polished, peened springs is active. Technicians are processing springs coiled from wire ranging between 0.030 and 0.5 in. in diameter. Spring and wire sizes are limited only by the dimensions of the electropolishing tank.

The principal processing variables that affect electropolishing results are time, current, and temperature. We have found that the best procedure is to follow the recommendations of the supplier of electropolishing concentrates used, especially considering the changes needed by different materials and the make-up of various solutions.

Similarly, proper shotpeening requires varying the size of the shot according to the size and type of material, and the size and complexity of the part.

Naturally, these springs can handle tough applications. One example is valve springs in racing-car engines. Initial tests showed that electropolished and peened springs were remarkably better than any other springs that had been tested. Results were confirmed by such springs installed in engines for a 400-mile race and for national drag competition. Accordingly, we are investigating other alloys and variations in processing to increase further fatigue strength and reliability of springs.