THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

SHOT PEENING OF SPRINGS

A Monograph

by

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1. INTRODUCTION

Shot peening is without doubt the most effective means of improving the fatigue life of springs. As a consequence of this, SRAMA has over the last 30 years continued to devote significant time and effort to research the process. This summary report seeks to bring together the major findings of this work to act as a reference document for SRAMA members wishing to discover more about shot peening.

The spring designer needs reliable data to enable him to quantify the improvement in fatigue performance obtained by applying shot peening, as well as a clear knowledge of the parameters which must be specified to ensure that the improvements in performance, which he has relied upon for his design, are produced in the springs themselves. The spring manufacturer needs to know how to set up and control the important parameters for the process to ensure optimum results.

Previous SRAMA reports have both investigated the details of the process in order to generate maximum performance, as well as carrying out many thousands of fatigue tests to quantify the improvements obtained.

2. SHOT PEENING AND SHOT BLASTING

Before moving on to consider in more detail the work which has been carried out, it is vitally important to establish the difference between shot peening and shot blasting. Both processes outwardly appear very similar inasmuch as they use the same equipment. There is therefore often a tendency amongst designers to confuse the two processes and to use the terms synonymously. In fact, as far as the fatigue life of springs is concerned, the two processes have completely opposite effects. Shot peening dramatically improves the performance of a spring, whilst shot blasting significantly reduces fatigue life.

Both processes consist of bombarding the surface of a spring with small particles of media at high velocity and, as stated earlier, identical equipment is used in both cases to achieve this. However, the nature of the media is very different in the two processes. In shot peening, rounded media are used in order to lock into the outer layers of the spring a beneficial compressive stress which opposes the in-service tensile stresses generating fatigue failures. The surface, when viewed under a microscope, shows rounded, shallow depressions where plastic flow has occurred as a result of the impact of the shot on the surface.

In shot blasting, very angular and abrasive media are deliberately used in order to scour and clean the surface of the spring to provide a firm key for a subsequent coating. The surface is left with sharp angular nicks which act as stress raisers in service and magnify the applied tensile stresses, leading to premature failures.

The designer and spring manufacturer must, therefore, clearly distinguish between these processes and, if shot peening is required in order to generate improvement in fatigue performance, the correct shot type must be selected and specified.

3. SHOT PEENING MEDIA

Three main types of media are used in shot peening:

1. Cast steel shot
2. Cut wire shot
3. Glass shot.

All three types are available in different sizes but glass shot is generally only available in smaller sizes and is only used for fine wire springs. For the majority of spring applications, therefore, the choice is between cut wire and cast steel shot. Very limited work carried out at SRAMA has not indicated a significant difference in the subsequent fatigue performance of springs shot peened under nominally the same conditions with the two media.

The main concern with cast steel shot is that it can be brittle at the high hardnesses necessary when shot peening relatively hard spring materials. It can therefore shatter into sharp pieces under the impact conditions which characterise the peening process. The sharp fragments of broken shot can then act in a similar manner to the angular media used in shot blasting with a resultant reduction in fatigue performance.

Cut wire shot is manufactured by cutting lengths of high tensile spring steel wire into short cylinders. At this stage the cylinders have very sharp edges and are frequently used for blasting processes. To make them suitable for use in shot peening applications, the cylinders of shot must be conditioned to round off the sharp corners. This is done either by firing the shot at steel plates, or by using the shot in a peening machine with scrap springs for 75/100 hours continuous operation.

The potential advantage of cut wire shot over cast steel is the former's higher ductility, which tends to make it wear gradually, remaining essentially rounded, rather than breaking down into fragments. Its main disadvantages are firstly, its greater cost and secondly, the fact that, unless it is thoroughly pre-conditioned, its cylindrical shape can still tend to generate stress raisers when new. If cut wire shot is used, it is therefore recommended that new shot be added gradually to replenish worn down shot on almost a continual basis.

For the designer, it is imperative that he use the terms ROUNDED Cast Steel Shot or FULLY CONDITIONED Cut Wire Shot when specifying shot peening.

4. SHOT SIZE

This factor is probably the most important variable in the shot peening process when seeking to produce the optimum life in springs. When other engineering components, such as gears, crankshafts etc, are shot peened, the section size of the component is invariably significantly greater than the size of even the largest shot. This, however, is not the case with springs. Recognising this, SRAMA has carried out a significant programme of work to investigate the shot size effect on a range of different compression spring designs and different materials (SRAMA Research Reports Nos. 217 and 267).

The clear finding of this work was that, in order to achieve maximum fatigue life, it is essential that the shot size selected must be less than 20% of the wire diameter of the spring. At 30% the fatigue performance begins to decline dramatically until at shot sizes greater than 75% of the wire diameter, the fatigue performance of shot peened springs is no better than that of unpeened springs. At ratios greater than 100% the lives of shot peened springs are actually less than those of unpeened.

At the other extreme, the work did not establish a minimum shot size ratio below which fatigue performance reduced. However, such a limit must exist since the depth of the beneficial compressive stress layer is linked to the shot size. This has been established by SRAMA in work described in Research Report No 161. The depth of the compressive stress layer is 0.4/0.6 of the shot size. In order to have a beneficial effect, the depth of this layer must be greater than any surface defect present in the unpeened surface. Most spring material specifications link allowable surface defects to the section size, so that the larger the section, the larger will be any allowable surface defects. As a consequence, if large section sizes are peened with relatively fine shot, there is a significant risk that the compressive stress layer will not exceed the depth of the surface defects. This will result in a reduction in fatigue performance.

A further consideration when selecting shot size is that the shot particles must be capable of peening the inside coil surface effectively. This means that the shot stream must pass through the coil gap at one side of the spring, and cross the inside coil diameter to the inner coil surfaces on the opposite side of the spring.

In order to pass through the coil gap without interference, the shot size must be significantly smaller than the gap itself. The UK military standard DEF 03-21 specifies that the shot size must be less than 25% of the coil gap.

This is the size limit also specified in the US military standard MIL-S-1316SA.

5. ALMEN ARC HEIGHT/EXPOSURE TIME

Once shot type and size have been selected, attention passes to the question of Almen Arc Height as measured by the Almen test. This test is a means of establishing the intensity of the shot blast and is used as a method of controlling the shot peening process to ensure full coverage of all the spring surfaces.

The test is specified in all three major national specifications on shot peening and comprises a standard Almen test strip which is mounted against a test block and shot peened along with the springs. Since only one face of the strip is exposed to the blast, the previously flat strip adopts a curve when released from the block after peening. This bow is a result of the compressive stresses induced beneath the exposed surface. The height of the bow measured across a standard chord on an Almen Gauge is, therefore, a measurement of the level of compressive stresses induced in the strip.

The more intense the blast, the greater are the compressive stresses induced within the strip and the greater is the Arc Height. As stated earlier, the Arc Height is also used to assess coverage on the spring surfaces. This is done by monitoring not the absolute value of the Arc Height, but the rate of increase of the Arc Height with time.

It is clear that an assessment of coverage is essential in the peening process. If insufficient coverage is achieved, then areas of the spring surface will remain unaffected by the peening effect, and premature fatigue failures will initiate from these unpeened zones. The springs must be exposed to the blast for sufficient time for all surfaces to receive adequate shot impacts to lock in the required compressive stresses. The rate of increase of Arc Height with time indicates when this situation is achieved since, once full coverage has occurred on the

Almen strip, further shot impacts cannot induce further compressive stresses. This is detected by a flattening in the rate of increase of Arc Height (see Fig 1). The exposure time necessary to obtain full coverage (or saturation, as it is commonly known) can then be estimated by ensuring that a doubling of exposure time on a strip causes no more than a small increase in Arc Height. This procedure is detailed in all three major national specifications covering shot peening. The percentage increase in Almen Arc rise allowed for a doubling of exposure time differs in these three specifications, with the DEF 03-21 and MIL-S-13165B standards allowing only a 10% increase whilst the SAE J808a allows a 20% increase. The effect of this is to require much longer exposure times for the two military standards. This is presumably to minimise the risk of insufficient coverage.

For many years, however, concern has been expressed that long exposure periods can lead to a condition known as overpeening. This condition is caused by shot impacts being superimposed on an already peened surface which, it has been proposed, can lead to the formation of laps and other surface defects as material plastically flows over previous impacts. These surface defects would act as initiation sites for fatigue cracks, thereby leading to premature failure in service.

SRAMA has in recent years undertaken a major programme of work to investigate the effect of exposure time on the fatigue life of springs.

This work is described in Research Report No 404 and has indicated that, at the long exposure times required by the 10% increase rule, there is a significant reduction in fatigue performance. At the much shorter exposure periods generated by the 20% standard adopted by the SAE specification, there was a general improvement in the fatigue performance of the springs. This work points to the need for careful control and optimisation of the exposure time.

The main problem which arises at short exposure times in batch peening is the difficulty in ensuring that all springs in the batch are exposed to the blast. It is precisely because of this problem that on-line peening has received close attention in recent years. Since each spring is peened individually, it is possible to ensure close control and repeatability in the exposure of each spring. However, due to the short time available for each spring within the blast, very high velocity shot streams are required. Work carried out at SRAMA (Report No 267) has shown that in general, high shot velocities can lead to a reduction in fatigue performance. Again, therefore, in on-line plants the optimisation of the exposure time is vital and must be very closely controlled.

6. POST PEENING STRESS RELIEF

Whilst shot peening provides a dramatic improvement in the fatigue performance of springs, it has the reverse effect on the relaxation resistance of springs (ie their ability to maintain load stability with time). This has been shown most clearly in SRAMA Report 267 which also demonstrates that the effect worsens with larger shot sizes. In addition, comparative relaxation data are presented in Reports 194 and 379. This effect can be countered to a large degree by subjecting the springs after peening to a low temperature stress relief at 225°C for 30 minutes. Report 161 also establishes that this has a beneficial effect on the fatigue performance of the shot peened springs. Such a treatment should therefore always be specified and carried out.

7. STRAIN PEENING

If the shot peening process is carried out while the spring is held under stress then a considerable further increase in life can be obtained beyond that produced by conventional shot peening. This process is known as strain peening and has been examined by SRAMA. Reports Nos 247 and 252 quantify the benefits to be obtained.

The main problem lies in the fact that each spring must be individually jigged to hold it under load during the peening process. This can be complex and expensive to carry out, particularly in batch type peening processes. The use of on-line processes, however, opens up the possibility of automating the clamping of the spring which makes the process cost effective on large batches. This has been applied for a number of years to parabolic tapered leaf springs.

With compression springs the closure of the coil gap whilst the spring is strained can make shot size selection more critical since the shot must penetrate through a reduced gap.

8. FATIGUE DATA FOR SHOT PEENED SPRINGS

The fundamental reason for specifying shot peening and the need for close control of the peening parameters is to maximise fatigue resistance. Over many years SRAMA has continued to collect data from the results of many thousands of fatigue tests which enable the designer to quantify the improvement in fatigue performance to be obtained by using the shot peening process.

A summary of all the Research Reports issued to date containing data on the fatigue performance of shot peened springs is presented here in tabular form (Table I). It must be borne in mind that fatigue data always contain a very large degree of scatter and, in recent years, SRAMA has begun to apply advanced statistical techniques to interpret the data and present not merely mean (50%) survival lines, but also 95% and 99% survival lines on the S/N curves and Goodman Diagrams produced. The table, therefore, indicates in column V whether or not statistical analysis has been carried out. A thorough explanation of the statistical techniques used is given in Research Report No 274.

The table is not presented in strict numerical order. The first main division is that of material type. In column I the report number is then given along with the wire sizes covered in the work (column II). The depth of the work is then summarised by indicating the initial stress levels used in the production of any S/N curves (column III) and the life cycles of any Goodman Diagrams contained within the report (column IV).

The last column of the table (column VI) provides an indication as to whether or not comparative data on unpeened springs are presented within the report in question.

9. REPORT LISTING

As a final aid, a full report listing is provided in Table II of all SRAMA Research Reports which contain some information on the shot peening process and its effect on spring performance. The listing is in strict numerical order and a good indication of the content of each report can be obtained from its title.

Table I - Fatigue Data on Shot Peened Springs

1. Cold Drawn Carbon Steel

	I	II	III	IV	V	VI
0.9% C continental music wire	131	2.64	77	NONE	NO	YES
EN 49D	148	3.25	77	10^7	NO	YES
BS 1408 C2	168	2.64	77, 154, 309	10^7	NO	YES
BS S202	186	4.00	100, 500	10^7	NO	NO
BS 1408 C2	195	2.00	100	NONE	NO	NO
BS 1408 C3	219	2.30	100, 300	10^7	NO	YES
BS 1408 C and D, R1 - R3	224	4.00	NONE	10^7, 10^6, 10^5	YES	YES
UHT 3	241	2.35	100, 500	10^7, 10^5	NO	YES
UHT 3	245	3.16	88, 438	10^7	NO	YES
BS 1408 M1 and M2	246	3.00	100, 500	10^7	NO	YES
BS 5216 HD3 and M4	277	2.65	100, 300	10^7, 10^6	YES	YES
BS 1408 B2	294	10.20	150	NONE	YES	NO
BS 5216 ND3	295	4.00	100, 500	NONE	YES	YES

2. Prehardened and Tempered Carbon Steel

Continental Gr II and III wires	131	2.64	77,	NONE	NO	YES
BS 2803 (1956) Gr I and II	225	4.00	NONE	10^7, 10^6, 10^5	YES	YES

3. Annealed Carbon Steel (Cold Coil)

BS S203	189	4.00	100, 200	10^7	NO	NO

Table I - Fatigue Data on Shot Peened Springs continued ...

4. Prehardened and Tempered Low Alloy Steel

	I	II	III	IV	V	VI
Chrome Vanadium (EN 50)	148	3.25	77	10^7	NO	YES
Silicon Chrome (EN 48A)	148	3.25	77	10^7	NO	YES
Silicon Chrome (EN 48A)	163	4.19	77	10^7	NO	YES
Chrome Vanadium (735A50)	248	2.60	100, 200	10^6	NO	NO
Chrome Vanadium (730A65)	317	2.50	100	NONE	NO	YES

5. Annealed Low Alloy Steel (Cold Coil)

	I	II	III	IV	V	VI
Chrome Vanadium (BS 1429: EN 47)	226	4.00	NONE	10^7, 10^6, 10^5	YES	YES
Chrome Vanadium (BS 1429: EN 50)	294	11.00	150	NONE	YES	NO
Carbon Chrome (BS 970: 527A60)	321	4.00	70, 150, 200	10^7, 10^6, 5.10^5, 10^5	YES	NO

6. Annealed Low Alloy Steel (Hot Coil)

	I	II	III	IV	V	VI
Silicon Manganese (BS 970: EN 45A)	167	26.40	77	NONE	NO	YES
Silicon Manganese (BS 970: EN 45A)	210	11.20	150, 300, 400	10^7, 10^6, 10^5	NO	YES
Silicon Manganese (BS 970: EN 45A)	294	12.80	100, 300	10^7, 2.10^6	YES	YES

Table I - Fatigue Data on Shot Peened Springs continued ...

7. Stainless Steel

	I	II	III	IV	V	VI
BS 2056 EN 58A	156	2.64	77	NONE	NO	YES
Armco 17/7 PH	198	4.00	100, 500	10^7	NO	YES
BS S205	206	4.00	100, 500	10^7	YES	YES
FV 520 (S)	211	4.00	100, 500	10^7, 10^6	YES	YES
BS 2056 EN 58A and 58J	227	4.00	NONE	10^7, 10^6, 10^5	YES	YES
Armco PH 15/7 Mo	256	2.35	100, 300	10^7, 10^5	NO	YES
Armco Nitronic 50 and 32	256	2.35	100, 500	10^7, 10^6, 10^5	NO	YES
BS 2056 EN 58A	295	4.00	100, 500	NONE	YES	YES
S301S21	315	2.61	100, 200, 300	10^6, 5.10^5, 10^5	YES	YES
BS 2056 302S26 Gr II	369	2.64	100	NONE	NO	YES

8. Miscellaneous

Titanium 314A	149	3.25	77	10^7	NO	NO
Maraging Steel 18% Ni Co Mo	279	2.65	100, 300, 500	10^7, 10^6, 10^5	NO	YES
Nimonic 90 and Inconel X750	285	1.63	100	NONE	YES	YES
Titanium 318	288	2.49	50, 100	10^7, 5.10^6	YES	YES

Table II - Shot Peening Reports Listing

Report No	Title	Date
101	The effect of scale removal prior to reheating for quenching on a 1% carbon spring steel	May 1958
124	Further studies on the effect of non-metallic coatings on the corrosion fatigue strength of a spring steel	Mar 1961
131	The effect of shot-peening on the fatigue properties of helical compression springs made from continental oil-tempered and patented hard drawn spring steel wires	Feb 1962
132	The effect of recarburisation prestraining and other surface conditions on the torsional fatigue strength of En 36 steel	Mar 1962
135	The effect of carbon restoration and shot peening on the fatigue strength of highly stressed heavy coiled compression springs	July 1962
147	The effect of industrial processing and surface treatments on the fatigue strength of hot-formed springs	Apr 1964
148	A comparison of the static mechanical and fatigue properties of three spring steel wires	May 1964
149	Titanium 314A wire and compression springs. I - The static and dynamic properties of 314A titanium shot peened wire and springs. II - A design comparison of cold drawn 314A and aged titanium with En 49D and En 58A wires as materials for springs	June 1964
156	Some static and fatigue properties of En 58A stainless steel spring wire to BS 2056	June 1966
159	Application of RARDE experimental Si-Cu-Mo steel. Pt 1 properties of material. Pt 2 properties of wire. Pt 3 properties of springs	May 1966
161	The effect of shot peening on the fatigue behaviour of Si-Mn spring steel	Sept 1966
163	The static and dynamic properties of springs made from a Continental oil-hardened and tempered spring steel wire	June 1967
167	The effect of industrial processing and surface treatments on the fatigue strength of hot formed springs	May 1968

Table II - Shot Peening Reports Listing (cont)

Report No	Title	Date
168	A comparison of the fatigue properties of springs made from electro-slag refined steel and conventionally melted steel to specification BS 1408C	Aug 1969
186	The fatigue properties of helical compression springs manufactured from S202 spring material	June 1971
189	The fatigue properties of helical compression springs manufactured from S203 spring material	July 1971
194	The stress temperature relaxation properties of some high temperature and corrosion resistant materials	Nov 1971
195	The fatigue properties of helical compression springs manufactured from shot peened patented and cold drawn spring steel wire	Dec 1971
198	The fatigue properties of helical compression springs manufactured from 17-7 PH wire	Jan 1972
206	The fatigue and associated mechanical properties of helical compression springs manufactured from S205 spring wire (Contract No K43A 65 CB43A2). Progress Report No 4	Aug 1972
210	The fatigue properties of heavy helical compression springs. Progress Report No 1 Phase 1 En 45A	Dec 1972
211	The fatigue properties of helical compression springs manufactured from FV 520(S) wire (Contract No K43A 65 CB43A2). Progress Report No 5	Dec 1972
217	An investigation into the effect of shot size in shot peening	Sept 1973
219	The effect of solid stress on the fatigue behaviour of springs manufactured from BS 1408C	Sept 1973
224	The production of spring fatigue data with statistical levels of confidence. Part 2 of 7 parts. The fatigue properties of springs manufactured from patented cold drawn steel spring wire to BS 1408 C and D	Feb 1974
225	The production of spring fatigue data with statistical levels of confidence. Part 3 of 7 parts. The fatigue properties of springs manufactured from oil hardened and tempered steel wire to BS 2803 Grades I and II	Feb 1974

Table II - Shot Peening Reports Listing (cont)

Report No	Title	Date
226	The production of spring fatigue data with statistical levels of confidence. Part 4 of 7 parts. The fatigue properties of springs manufactured from chrome-vanadium wire to En 47 Grade I to BS 1429	Feb 1974
227	The production of spring fatigue data with statistical levels of confidence. Part 5 of 7 parts. The fatigue properties of springs manufactured from En 58A and En 58J stainless steel wire to BS 2056	Feb 1974
229	The production of spring fatigue data with statistical levels of confidence. Part 7 of 7 parts. Spring design data	Feb 1974
234	The effect of hot prestressing on the fatigue and relaxation properties of helical compression springs manufactured from low alloy steel wire	Oct 1974
241	An evaluation of ultra high strength carbon steel wire for springs	Nov 1974
245	The properties of ultra high strength carbon steel wire and springs	May 1975
246	The properties of BS 1408M R1 and R2 wires and springs	June 1975
247	The effect of strain peening on the fatigue properties of flat springs	June 1975
248	The effect of hot and cold prestressing on the fatigue and relaxation properties of compression springs made from Cr-V steel wire	June 1975
252	The effect of strain peening on the fatigue properties of helical compression springs made from pre-hardened and tempered carbon steel wire	Oct 1975
256	An evaluation of three Armco stainless steel materials for springs	Feb 1976
266	The low temperature heat treatment of springs manufactured from patented cold drawn carbon steel wire	Nov 1976
267	Shot peening and the effect of shot size on spring performance	Nov 1976

Table II - Shot Peening Reports Listing (cont)

Report No	Title	Date
277	The fatigue properties of springs manufactured from material to BS 5216 HD3 and M4	July 1977
279	The fatigue and relaxation properties of maraging steel springs	July 1977
282	Assessment of strain peening applied to compression springs torsion bars and flat springs	Oct 1977
284	On the mechanism responsible for the changes in elastic and relaxation properties with stress strain and temperature variations in spring materials	Oct 1977
285	The room temperature and high temperature fatigue and dynamic relaxation properties of helical compression springs manufactured from Nimonic 90 and Inconel X750 wires	Nov 1977
288	The fatigue and relaxation of high strength titanium 318 alloy springs	Feb 1978
291	The mechanical properties of three heavy spring steels at two hardness levels	Mar 1978
294	The fatigue properties of medium sized helical compression springs	June 1978
295	The fatigue characteristics of compression springs with limited life operation	June 1978
315	The fatigue and relaxation behaviour of helical compression springs coiled from Type 301 hard drawn stainless steel wire	Dec 1979
317	The effect of the order of hot prestressing and shot peening on the fatigue and relaxation properties of low Cr-V valve springs	Sept 1979
319	The effect of shot peening time on the fatigue and relaxation properties of low Cr-V valve springs	Nov 1979
321	The fatigue and relaxation properties of shot peened helical compression springs made from 527A60 carbon-chromium wire	Feb 1980
359	The effects of Ion-nitriding upon the fatigue properties of springs made from chromium-silicon wire	Sept 1983
369	The effect of surface roughness electropolishing and shot peening on the fatigue properties of austenitic stainless steel springs	Mar 1984

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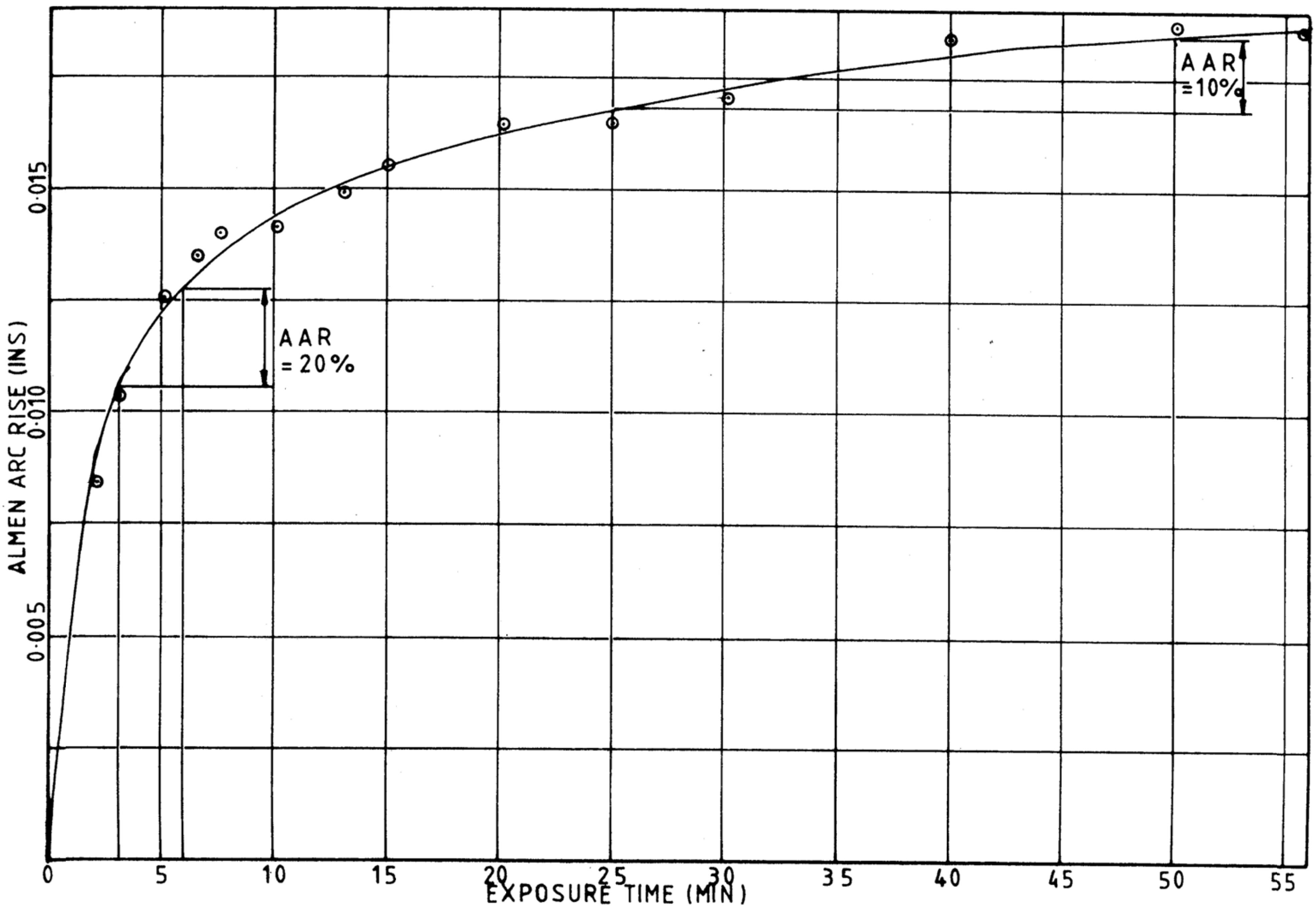

Fig 1 ARC RISE CURVE FOR S.R.A.M.A. SHOT PEENING MACHINE