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O T T A W A July 24th, 1942.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1266.

Examination of Two Steel Rings.

(Copy No. 10.)

BUREAU OF MINES
DIVISION OF METALLIC MINERALS

ORE DRESSING AND
METALLURGICAL LABORATORIES

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
MINES AND GEOLOGY BRANCH

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Investigation No. 1266.

Examination of Two Steel Rings.

Origin of Material and Object of Investigation:

On June 1st, 1942, two steel rings, marked respectively "A" and "B," were received from Brigadier General G. P. Morrison, Director of Technical Research, Department of National Defence (Army), Ottawa, Ontario, for examination.

Description of Rings:

Ring "A" (mark on surface, "Test 808 Run/2 ring A") was 0.843 in. thick and had an inside diameter of 4.7555 in. The outside shape of the ring is conical, with the small diameter 7.00 i.. and the large diameter 7.117 in.

Ring "B" (mark on surface, "Test 808 Run/2 ring B")

(Description of Rings, cont'd) -

was 0.830 in. thick with a 4.7835 in. inside diameter, and 6.8750 in. and 7.0625 in. (conical shape) outside diameters.

Figures 1 and 2 are views of the rings as received.

The dimensions of the rings were taken after slight machining of the cylindrical and conical surfaces, the machining being done so as to facilitate the taking of accurate measurements.

Figure 1.

RING "A"

A view of "A" showing concentric circled temper colours.

(Approximately ½ actual size).

Figure 2.

RING "B"

A view of "B" showing concentric circled temper colours.

(Approximately ½ actual size).

(Description of Rings, cont'd) -

The flat surfaces of both sides of the rings show the temper colours that were produced as a result of the high frequency induction treatment.

The disposition of colours on the flat surfaces of Rings "A" and "B" is shown in Table I.

Table I.

The Distribution of Temper Colours.

Successive number of colour strip	RING A				RING B			
	WIDE SIDE		NARROW WIDE		WIDE SIDE		NARROW SIDE	
	Width, in.	Colour	Width, in.	Colour	Width, in.	Colour	Width, in.	Colour
1	15/32	0	12/32	0	15/32	6	8/32	3
2	3/32	1,2	3/32	1-4	7/32	9	1/32	6
3	2/32	3,5	2/32	6	19/32	10	2/32	3-5
4	2/32	6	1/32	4,5			6/32	6-8
5	1/32	4,5	8/32	7,8			9/32	9
6	5/32	7,8	6/32	9			15/64	10
7	4/32	9	4/32	10				
8	6/32	10						

As a guidance the various temper colours and the temperatures at which they are produced are given in Table II. This table is for the ordinary type of heat treatment and should not be considered as exactly applying to induction heat treatments where heating times are very short.

Table II.

Scale of Temper Colours.

No.	Temper colour	Temperature °F.	Temperature °C.
1	Lemon yellow	430	221
2	Light straw	458	236.6
3	Dark straw	478	247.7
4	Purple reddish	523	272.8
5	Purple bluish	551	288.4
6	Blue	572	300.0
7	Grey blue	603	317.3
8	Greenish blue	627	330.6
9	Grey	700	371.1

(Description of Rings, cont'd) -

In Table I, "O" was used to mark the surface without temper colour, and 9 and 10 to mark the dark-grey and dark surfaces for the temperatures above the scale of temper colours.

Views (to size) of the segments of Rings "A" and "B", with temper colours, are shown in Figures 3 and 4.

Figure 3.

Segment of Ring A, showing distribution of temper colours.

(Approximately actual size).

Figure 4.

Segment of Ring B. showing distribution of temper colours.

(Approximately actual size).

Hardness Tests:

Vickers hardness values have been taken in a radial direction across the flat surface of both rings. The distribution of these hardnesses is shown in Table III below.

Table III.

Vickers Hardness Results (50-Kg. load).

Hardness readings, taken every millimetre, starting from inside of ring, mm.	Ring A	Hardness zones	Ring B	Hardness zones
1	184	Inside	210	Inside
2	186	Soft zone, 23 mm. thick	206	Soft zone 13 mm. deep.
3	184		201	
4	181		190	
5	188		207	
6	188		207	
7	187		205	
8	185		205	
9	186		201	
10	186		204	
11	186		204	
12	185		205	
13	189		217	
14	189		255	Transition zone, 7 mm. thick.
15	179		259	
16	186		285	
17	189		292	
18	195		302	
19	200		351	
20	224		452	
21	208		681	Very hard zone, 6 mm. thick.
22	208		696	
23	353	Transi-tion zone®	757	
24	656		761	
25	779	Very hard, 5 mm. thick.	788	
26	757		779	Outside
27	757		Taken on small side of the cone	
28	736			
29	740			
	Taken on wide side of the cone			

® 2 mm. thick.

Chemical Analysis:

This was taken only from Ring B.

Carbon	-	0.58 per cent
Nickel	-	None detected.
Chromium	-	Trace.
Molybdenum	-	None detected.

Tensile Tests:

Small pieces of the type that can be broken in the Hounsfield tensometer were cut from the rings. The locations from which these pieces were taken were as follows:

Ring A:

Test Pieces Nos. 1 and 2 were taken in a tangential direction, 5/16 in. from the inside edge, as were also Test Pieces Nos. 3 and 4 except that they were 3/8 in. from the edge.

Test Piece No. 7 was taken in a direction vertical to the flat surface of the ring, 5/16 in. from the inside edge.

Ring B:

Test Pieces Nos. 5 and 6 were taken in tangential directions, 5/16 in. from the inside edge. Test Piece No. 8 was taken from the vertical direction, 5/16 in from the inside edge.

The results of the tensile tests are shown in Table IV.

(Continued on next page)

(Tensile Tests, cont'd) -

Table IV.

Tensile Test Results.

No.	Diameter, inch	Reduction in area, per cent	Elongation,® per cent	Yield strength, p.s.i.	Ultimate strength, p.s.i.	Direction
Ring A, 1	0.154	37.5	11.6	94,000	102,375	Tangential
2	0.160	30.0	11.9	97,500	103,000	"
3	0.160	32.5	11.9	92,000	105,000	"
4	1.160	30.5	11.73	96,000	105,000	"
Ring B, 5	1.160	37.0	12.3	95,000	103,000	"
6	1.160	37.0	14.0	98,000	104,000	"
Average		34.8	12.24	95,500	103,730	
Ring A, 7	0.1600	25.0	12.33	98,000	105,000	Longitudinal
Ring B, 8	0.1605	25.0	12.2	98,000	107,000	
Average		25.0	12.26	98,000	106,000	

® Elongations measured for Samples 1 to 7 were on gauge lengths of 0.625 in., and 0.56 in. for Samples 7 and 8.

Macro-Examination:

The macro-etching performed on Ring A, etching in a reagent composed of 6 g. cupric chloride, 6 g. ferric chloride, 10 ml. hydrochloric acid and 100 ml. ethyl alcohol, has shown the sharp difference in colours of the flat side of the ring. See Figure 5.

The dark layer on the outside part of the surface is 9/32 in. wide, which is about the same thickness as the very hard layer shown in Table III.

(Continued on next page)

(Macro-Examination, cont'd) -

Figure 5.

Segment of Ring A
after the nacro-etching

(Approximately actual size).

Microscopic Examination:

Cross-sections of each ring were examined under the microscope. Figures 6 to 9 show photomicrographs taken from Ring B at points where characteristic changes in hardness occurred. Structures shown are similar to those observed in Ring B, although the various structures were not in the same locations for both rings.

The structure shown in Figure 6 is martensite, having hardness range from 788-779. Figure 7 shows the austenitic grain size in this range to be quite large.

Figure 8 shows a mixed structure, mainly martensite-troosite, zones with hardness range from 452-681.

The pearlite-ferrite structure (see Figure 9) was found in zones with hardness range from 190-217.

(Continued on next page)

(Microscopic Examination, cont'd) -

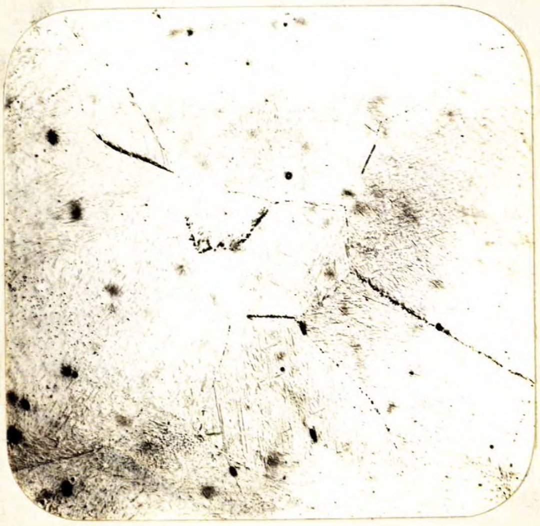
The non-metallic inclusions in Rings A and B, examined on longitudinal samples at X100 magnification, were found to be uniformly distributed, small, and numerous.

Figure 6.

X500, etched in 2% nital.

Martensitic structure, coarse grains.

Figure 7.



X100, electro polished and lightly etched in 4% picral.

Coarse grains of martensite.

Grain size No. 2.
A.S.T.M., E-19-39T.

(Microscopic Examination, cont'd) -

Figure 8.

X500, etched in 4% picral.

Martensite and troosite.

Figure 9.

X100, etched by electro-polishing.

Coarse grains - pearlite and ferrite.

Layer Thicknesses:

The thicknesses of the various hardness zones of the rings, as determined by hardness tests, microscopic examination, macro-etching and temper colour observations, were as follows:

Table V.

Ring	Kind of Material	Vickers hardness	Thickness of layer, in mm.	Remarks
A	a) Inside layer of soft material	181-224	23	Taken on wide side.
	b) Layer of medium hard material (the transitory layer between very hard and soft material	353-656	2	"
	c) Outside layer of very hard material	736-779	5	"
B	a) Inside layer of soft material	190-217	13	Taken on small side.
	b) Medium hard	253-681	7	"
	c) Outside layer of very hard material	738-779	6	"

Discussion of Results:

The rings were produced from a plain 0.58 per cent carbon steel. The ultimate stress in the soft ring material is 103,730 p.s.i. in the tangential direction and 106,000 p.s.i. in the longitudinal direction. These values are what would be expected in SAE 1060 steel.

Analysing the tensile test results, we may note that the reduction of area in tangential samples (Nos. 1 to 6) is an average of 34 per cent and in the longitudinal directions is 25 per cent. This difference points to the possibilities

(Discussion of Results, cont'd) -

that the rings were forged on a mandrel.

The result of the microscopic examination and the appearance of the cylindrical surfaces of the tensile samples and their appearance of fracture indicated a corase-grained material. This material was in the normalized condition before the application of the induction heat autofrettage. The large grain size indicates that the temperature was probably high.

The distribution of the Vickers hardness is in accordance with the gradation of the structure from martensite to annealed pearlite-ferrite. Results of macro-etching and temper colour observations also check these hardness tests.

The rings exhibited characteristics of induction heating.

Ring B apparently was more intensively heated than Ring A. The depth of the layer heated above the critical temperature before quenching in water is 7 mm. for Ring A and 13 mm. for Ring B, the depth including both fully hardened and semi-hardened zones (see Table III).

Hardness distributions and structure variations were found to be symmetrical with the axes of the rings.

General Remarks about the Possibility of Employing the New Methods of Induction Heating Autofrettage:

From the nature of the temperature distribution by the induction heating, it is possible to expect the autofrettage effect, taking into consideration the theoretical calculations of the distribution of thermal stresses in hollow cylinders. (See papers 1, 2, 3).

(Continued on next page)

(General Remarks about the Possibility of Employing the New Methods of Induction Heating Autofrettage, cont'd) -

1. The Thermal Stresses in Circular Cylinders Concentrically Heated, by Charles H. Lees, Proceedings of Roy. Soc., London, 1922, pp. 411-430.

2. The Calculation of Temperature Stresses in Tubes, by L. H. Barkers, in ENGINEERING, 1927, p. 443.

3. Strength of Materials, Part II, S. Timoshenko, 2nd Edition, pp. 258-264.

The heating of Rings A and B above the critical temperature, before quenching, results in the very hard material which is not machinable - an objectionable feature.

It would be desirable to apply such a heat treatment as would stress a ring or gun-barrel without producing any exterior hard layer.

Using the known method of thermal stress calculation, we should notice that by ratio D_o/D_i = 1.5 (D_o = outside diam., D_i = inside diam.) and by coefficient

$$\frac{m \cdot E \cdot d}{m - 1} = 600$$

m = Poisson's ratio.
E = Modulus of elasticity.
d = Coefficient of expansion.

the maximum tangential temperature stress in a cylinder due to the radial temperature difference was found to be 335 pounds per square inch per 1 degree Centigrade of radial temperature difference.

This figure gives an indication as to the required temperature difference that would be required if the induction autofrettage effect were to be obtained. (This does not take

(Discussion of Results, cont'd) -

into account the influence of a contraction by rapid cooling.)

The kind of stress distribution produced by radial temperature difference is shown in the following table:

Kind of Stresses	Direction of stresses	Position of stresses
Tangential	Tension	Inside
Tangential	Compression	Outside
Longitudinal	Tension	Inside
Longitudinal	Compression	Outside
Radial	Tension	Inside Outside

It would appear then that the kind of stress distribution produced by differential induction heating will produce an autofrettage effect.

The quantity and size of samples submitted did not permit a standard residual stress test. A substitute arbitrary test was performed and is described in letters attached to this report. (See Pages 17 to 19).

The distribution and magnitude of residual stresses may be determined by employing a method which involves a machining of layer after layer from outside or from inside of the ring and taking suitable measurements after removal of each layer.

It is imperative that samples should all be machined before heat-treatment to exactly the same inside and outside diameter dimensions.

Because of the complicated nature and expense of this test, it might be useful to discuss the dimensions and quality of necessary samples with the maker.

(Continued on next page)

(Discussion of Results, cont'd) -

It might be useful to determine the influence of the heat treatments outlined below on the distribution and intensity of the residual stresses:

a) To inductively heat a ring or section of a gun barrel to a suitable temperature and then cool only in a quiet air or in an air stream. It is felt that temperature differential alone might be sufficient to stress the ring and that stresses put into the inner barrel material might not be relieved by conduction heat. No outer hardened zone would be produced in this method.

b) Heat to a temperature in the neighbourhood of, or above the critical and then cool slowly through the critical range, then quench. This should eliminate hardened material on outside layers of the ring yet maintain a good stress condition.

c) Completely heat-treat the ring before induction heating, then apply the induction heating up to the neighbourhood of the critical temperature. This would avoid the complete transformation of outside layers of the ring and consequently eliminate the outer hardened zone, while still maintaining satisfactory stress conditions.

d) To raise the temperature difference between outside and inside walls of the barrel by employing the air, etc., cooling of the inside wall of the barrel during induction heating. By so doing, magnitude of stress differential should be increased.

e) To determine the influence of drawing on residual stresses distribution.

(Continued on next page)

(Discussion of Results, cont'd) -

It might be desirable to take the exact dimensions of inside and outside diameter and length of a ring or gun barrel in three stages of process: before heating, during heating (inside), and after cooling.

The relations between these figures may give to us some idea as to the kind and intensity of stresses and the way to control them.

This method would appear to be worthy of further experimental test, which should involve a thorough study of residual stresses and metallurgical considerations.

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552 Booth Street,
Ottawa, Ontario,
July 11th, 1942.

Memorandum:

To: Brigadier General G. P. Morrison,
Director of Technical Research,
Department of National Defence (Army).

Re: Preliminary Report on Rings from Gun Barrels produced by a New Method to Produce the Effect of Autofrettage.

In connection with the two rings which we have received from you for testing, we would like to inform you that before starting the metallurgical tests we performed, for experimental purposes, some approximate testing by simplified methods to determine a few figures of residual stresses in both rings (marked respectively A and B).

In order to obtain approximate figures of residual stresses without destroying the material itself, the rings were divided and split. The ring A was first divided into two concentric rings, A-1 inside ring, and A-2 outside ring, by a cut parallel to the axis of the ring. The two rings A-1 and A-2 obtained in this way were afterwards split. Ring B was split only once. The diameters of all rings were measured before and after dividing by the National Research Council Gauge Laboratory.

For approximate calculation of stresses freed by dividing ring A into A-1 and A-2, we may use the equation:

$$t_a = -Eb$$

where E is the modulus of elasticity and b the change of diameter.

We obtain the following values fot t_a:

For inside ring A-1 -62,500 lb/sq.in.
For outside ring A-2 +50,500 lb/sq.in.(difficulty in measurement because of conic surface).

Afterwards the rings A-1 and A-2 were split and the values of the remaining residual stresses, if we may call them so, may be calculated approximately from the equation

$$t_b = E \times d \frac{D_1 - D_0}{D_1 \cdot D_0}$$

where d is the thickness of the ring, D_0 mean diameter before splitting and D_1 mean diameter after splitting.

COPY

Memorandum July 11th, 1942.

We obtained t_b values of +6020 lb/sq.in. for the inside ring A-1 and -54,200 lb/sq.in. for the outside ring A-2.

As previously mentioned, Ring B was split only once through the whole thickness, in order to conserve the material for further metallurgical tests. From the difference of diameters of ring B before and after splitting, we have

$$t_b = E.d \frac{D_1 - D_o}{D_1 \cdot D_o}$$ giving a result of

-38,940 lb/sq.in. in the outside layer of the ring.

From the above approximate figures which are rather of guidance value and are given for your advance information, we may suppose that the distribution of the residual stresses is, in this case, rather complicated.

Without going into any further analysis of the results obtained from this approximate determination of stress values, we may in the present stage of this test work say that the inside part of the ring is under compression from the outside part.

For accurate determination of residual stresses separate rings of the material will be required for each stress test.

We shall give you the remaining details of stress tests and results of tests on the material of the two rings as soon as they are completed.

We have checked our equipment for performance of these tests and hope to be able to make an arrangement with the National Research Gauge Laboratories for the necessary measurement.

Because of the complicated nature and expense of these tests, it might be useful to determine the dimensions and quality of necessary samples with the maker.

C. S. Parsons,
Chief of Division.

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552 Booth Street,
Ottawa, Ontario,
July 13, 1942.

Brigadier-General G. P. Morrison,
Director of Technical Research,
Dept. of National Defence,
Room 507, New Post Office Building,
Ottawa, Ontario.

Attention: Lt.-Col. H. R. D. Harris.

Dear Sir:

Further to our letter of July 11th, 1942, and using the observations from our experimental stress tests, when performing the metallurgical tests of the material itself, we are giving below the details of ring samples for a stress test:

For the determination of the residual stresses in the tangential and radial directions, we would like to have for each kind of experimental heat treatment three rings, two for the stress test and one for the metallurgical test. These rings should be taken from the same forging piece and be heat-treated together at the same time. The machining and grinding of the rings should be within an accuracy of as near as possible to one ten-thousandth of an inch. The outside and inside surfaces should be concentric and cylindrical. Lately the rings delivered have been conical on the outside, and this makes the calculation of stresses difficult. The width of each ring should be two inches.

For the determination of the stresses in all three directions, that is, longitudinal, tangential and radial, it is necessary to keep, in the preparation of the sample, the same conditions as stated before. The length of these samples should be three times the outside diameter.

We would like to have with each ring, preferably attached thereto, its full chemical analysis.

Yours very truly,

C. S. Parsons,
Chief of Division.

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