

16 May 1942

NRL Report No. M-1876

NAVY DEPARTMENT

FR-1876

Report On

The Effect of Cold Working on the
Magnetic Properties of Some Austenitic Manganese Steels

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages: Text - 4 Tables - 2 Plates - 8

Authority: Bureau of Ordnance Project Order 2151 - Ord of 7 August 1941.

Date of Test: March - April 1942.

Prepared by: Louis A. Carapella, Associate Metallurgist

Reviewed by: F. M. Walters, Jr., Senior Metallurgist
Superintendent, Division of Physical Metallurgy

Approved by: H. G. Bowen, Rear Admiral, USN, Director

Distribution:
BuOrd (5)
BuShips (2)

Distribution Unlimited

hsl

Approved for
Public Release

TABLE OF CONTENTS

<u>SUBJECT</u>	<u>PAGE</u>
Abstract	1
Authorization	1
Statement of Problem	1
Known Facts Bearing on Problem	1
Experimental Work.	2
Discussion of Results Obtained	2
Conclusions	3
Recommendations	4
References	5

APPENDICES

Chemical Analysis of Material Used	Table 1
Summary of Results	Table 2
Fahy Simplex Permeameter	Plate 1
Magnetic Tests 29, 30, and 31 - Specimen No. 150 (Hadfield Steel) with 12%, 27%, and 34% cold reductions	Plate 2
Magnetic Tests 32, 33 and 34 - Specimen No. 151 (Jessop Steel) with 15%, 23% and 48% cold reductions	Plate 3
Magnetic Tests 35, 36 and 37 - Specimen No. 152 with 12%, 23%, and 36% cold reductions	Plate 4
Magnetic Tests 38, 39, and 40 - Specimen No. 153 with 12%, 25%, and 33% cold reductions	Plate 5
Magnetic Tests 41, 42, and 43 - Specimen No. 154 with 13%, 26%, and 38% cold reductions	Plate 6
Magnetic Tests 44, 45, and 46 - Specimen No. 155 with 14%, 25% and 40% cold reductions	Plate 7
The Variations of Permeability in Weak Magnetizing Fields with Successive Reductions in Cross-Sectional Area by Cold Swaging.	Plate 8

ABSTRACT

Non-magnetic armor plate is usually made from austenitic steels which when cold worked, tend to become magnetic. Samples from a number of widely different types of austenitic alloys suitable for non-magnetic armor were subjected to varying degrees of cold reduction, and studied magnetically. It was found that the high carbon manganese alloys have a great capacity of acquiring high surface hardness upon deformation and of still retaining their weak magnetic characteristics; the low carbon alloys, on the other hand, are weakly magnetic for small amounts of cold working but become increasingly magnetic with further reductions. In any case, these alloys are all much less magnetic than armor of the "STS" type.

THE EFFECT OF COLD WORKING ON THE
MAGNETIC PROPERTIES OF SOME AUSTENITIC MANGANESE STEELS

AUTHORIZATION

1. This investigation was authorized by the Bureau of Ordnance Project Order 2151 Ord. of 1 August 1941, and represents a second magnetic investigation conducted under this authorization. The first was devoted to a study of the influence of heat treatment on the magnetic properties of some armor-plate steels and is given in NRL Report No. M-1842. (1)

STATEMENT OF PROBLEM

2. Non-magnetic armor plate is generally made from austenitic steels. The magnetic properties, however, tend to change when these steels are cold worked by rough handling in shipping and erection, or by attack by projectiles.

3. The ballistic properties of austenitic steels as quenched are equal to those of "STS" of the same hardness, but this hardness is lower than that of homogeneous light armor. Austenitic alloys can be hardened by heat treatment but they become magnetic, and so far attempts to improve ballistic properties by alloying have not been successful in developing the hardness desired. However, the proper degree of cold work raises the hardness and improves the ballistic performance of austenitic alloys without causing them to become too magnetic. Cold worked Hadfield steel has been used extensively for light armor.

4. The purpose of this investigation was, therefore, to determine what differences might exist in the response to cold work of a number of widely different types of austenitic alloys which may be considered for non-magnetic armor.

KNOWN FACTS BEARING ON THE PROBLEM

5. Austenitic alloys (with more than seventy-five per cent iron) are non-magnetic; however, they are metastable at room temperature and decompose to alpha, at least partially, when cold worked or when held at temperatures in the two phase region. Only the alpha phase is ferromagnetic at room temperature; whereas, the gamma is not. Cold work (2)(3) causes alpha to decrease its permeability, and increase its residual induction, coercive force and hysteresis loss, the only magnetic property not affected is saturation intensity. Hence, the measured magnetic properties of these alloys are actually the sum of two factors: (a) the amount of alpha present, and (b) the extent to which the alpha lattice is distorted.

6. One type of austenitic alloy, Hadfield steel, owes its austenitic character to the carbon which it contains as well as the manganese. The alloy must, however, be quenched from a fairly high temperature for it to be completely austenitic and non-magnetic. On the other hand, high manganese (16 to 25%) low carbon alloys contain two phases (chiefly gamma and some

epsilon) both of which are non-magnetic. (4) The gamma phase in these alloys transforms upon cold working, but no evidence is available which indicates that the epsilon phase upon severe distortion transforms either wholly or partially to a ferromagnetic state.

EXPERIMENTAL WORK

7. A series of widely different types of austenitic manganese steels having the compositions shown in Table 1 were selected for this investigation. Alloys No. 150 (Hadfield steel) and No. 151 (Jessop steel) were from commercial stock, the rest from experimental heats. From each of these steels, rods 1/2" in diameter and 10" in length were prepared and later heat treated by austenitizing each at the proper temperature for one hour and water quenching. In every case, the bars were sensibly non-magnetic (highly paramagnetic) in the "as quenched" state, but upon progressive cold working, they became more and more ferromagnetic.

8. As a means of studying quantitatively the influence of cold working on the magnetic properties of these steels, samples were all cold swaged in a rotary swaging machine. (5) The amount of cold work was measured in terms of per cent reduction in cross-sectional area of the originally underformed austenitic bars. After each reduction, the specimens were measured for size, magnetically analyzed, and then cold swaged for further reduction.

9. The magnetic properties were determined with a Fahy Simplex permeameter (6) of the type shown in Plate 1. This apparatus is not particularly well suited for measuring paramagnetic materials, but may, however, be used for weakly ferromagnetic ones. For this reason, no attempt was made to determine the paramagnetism of these alloys. The estimated accuracy of the apparatus, based on repeated observations was about 20 per cent for weakly magnetic alloys and about 5 per cent for those that were strongly ferromagnetic. All measurements were made at room temperature, (about 25° C).

DISCUSSION OF RESULTS OBTAINED

10. Shown on Plates 2 to 7, inclusively, are the normal induction curves and hysteresis loops* as determined from the magnetic analysis of a series of cold swaged austenitic alloys. Increases in permeability, residual induction, coercive force, and hysteresis loss were generally experienced upon cold working. As it may be seen from the normal induction curves, magnetic saturation was far from realized in many cases because of the difficulty with which the alloys were magnetized. Higher magnetizing fields are necessary for saturation.

11. The decomposition of the austenite upon cold working to a ferromagnetic phase appears not so pronounced in the high carbon manganese alloys as in those of lower carbon content. Apart from this generality, nothing specific can be deduced as to the influence of each element on the austenite

*On each plate, the hysteresis loops are given in the upper portion, and the normal induction curves in the lower.

decomposition with deformation due to the variety in composition which exists among the alloys. However, there are two alloys (see Table 1, Nos. 153 and 155) similar in composition, from which it is evident that the molybdenum tends to favor the decomposition to a ferromagnetic state.

12. A complete summary of magnetic characteristics for these steels is given in Table 2. These data have been calculated in the manner described in NRL Report No. M-1842, page 2, paragraph 10. (1) By contrast, the alloys are much less magnetic than armor of the "STS" type. Some values for "STS", taken from the report just mentioned, are given below for comparison:

BHN = 315 (or RC 43)	$B_r \times H_c = 203,000$
$\mu \text{ max} = 1150$	$(BH) \text{ max} = 99,000$
$B_r = 13,000$	$k = 0.476$
$H_c = -16$	$B = 20,800 (H = 260)$

13. In actual use, armor plate is rarely subjected to magnetizing fields stronger than those of the earth. Results of this investigation show that the normal magnetic induction may be assumed as a linear function for most cases in very weak fields up to a strength of 10 oersteds. The permeability of these steels may then be regarded the same at relatively weak magnetizing fields as at a field of 10 oersteds. The change of permeability with cold working is shown in Plate 8. Those steels having a permeability of less than 1.08 are considered as non-magnetic, between 1.08 and 2.00, as weakly magnetic, and above 2.00 as magnetic. In weak magnetizing fields, the high carbon manganese alloys are feebly magnetic for all reductions up to 48 per cent. The low carbon manganese alloys on the other hand, are weakly magnetic after about 5 per cent reduction and become increasingly magnetic beyond 10 per cent.

14. Cold working was carried far beyond the hardness which gives the best ballistic performance for the thickness in which non-magnetic armor is used, 350 to 430 Brinnell (37 to 45 Rockwell "C" scale). Consequently, the surface brittleness developed by some of the alloys (particularly the low carbon alloys) on the highest reductions may have no bearing on their suitability as non-magnetic armor.

15. It is interesting that the Hadfield steel, which is the least expensive of the steels investigated, hardened under cold work more rapidly with per cent reduction, developed a higher hardness, and at the same time was least affected magnetically.

CONCLUSIONS

16. From this investigation of the influence of cold working on the magnetic properties of a series of widely different austenitic manganese steels, it may be concluded:

- (a) That increases in permeability, residual induction,

force, and hysteresis loss were experienced;

- (b) That saturation was never realized for the magnetizing field used (typical of highly distorted or weakly ferromagnetic materials);
- (c) That these alloys are all much less magnetic than armor of the "STS" type;
- (d) That permeability may be regarded the same for relatively weak magnetizing fields as for a field of 10 oersteds;
- (e) That austenite decomposition upon deformation to a ferromagnetic phase is not as pronounced in high carbon manganese alloys as in lower carbon alloys; and,
- (f) That all of the steels, except No. 155 (high molybdenum) can be cold worked to an extent sufficient for ballistic purposes without becoming more than feebly magnetic (permeability less than 2).

RECOMMENDATIONS

17. In view of the lower cost and excellent resistance to becoming magnetic by cold work, it is recommended that consideration be given to cold worked Hadfield steel for non-magnetic armor.

REFERENCES

- (1) L. A. Carapella and H. F. Kaiser, "The Influence of Heat Treatment on the Magnetic Properties of Some Armor-Plate Steels of the 'STS' and N-A-X Types", NRL Report No. H-1842, February 1942.
- (2) H. H. Gries and H. Esser, "Magnetische Messeingen an Eisenviel - und Eisenlinkristallen mit einem neuartigen magnetischen Spannungsmesser", Archiv f. Elektrotechnik, vol. 22, 1929, pp 145-152.
- (3) L. A. Carapella, Discussion on C. S. Smith, "Magnetic Studies on Precipitation of Iron in Alpha and Beta Brass", Trans. American Institute of Mining and Metallurgical Engineers, vol. 144, 1942, (to be published soon).
- (4) F. M. Walters, Jr. and J. F. Eckel, "Alloys of Iron and Manganese - Part X, Thermomagnetic Analysis of Binary Alloys of Iron and Manganese," Trans. A. S. S. T., Vol. 21, 1933 pp. 1016 - 1020.
- (5) W. L. Bowen, Jr. "Swaging", Metals Handbook, American Society for Metals, Cleveland, Ohio, 1939 edition, pp. 884-885.
- (6) R. L. Sanford, "Magnetic Testing" Circular of the National Bureau of Standards C415, 1937, pp. 14-19.

TABLE I
Chemical Analyses

Composition	SPECIMEN NO.					
	(a) 150	(b) 151	(c) 152	153	154	155
C	1.32	0.35	0.30	0.06	0.03	0.07
Mn	12.4	11.9	6.83	17.82	17.39	17.42
Si	0.27	0.22	--	0.11	0.24	0.12
Ni	0.11	3.15	8.97	--	--	--
Cr	--	4.40	8.97	--	--	--
Mo	--	0.74	--	--	--	1.70
V	--	0.16	--	--	--	--
S	0.05	--	--	--	--	--
P	0.10	--	--	--	--	--
Ti	--	--	--	--	0.02	--
N ₂	--	--	--	--	0.064	--

NOTE: (a) Hadfield Steel (b) Jessop Steel (c) British non-magnetic armor steel of "8-8-8" type.

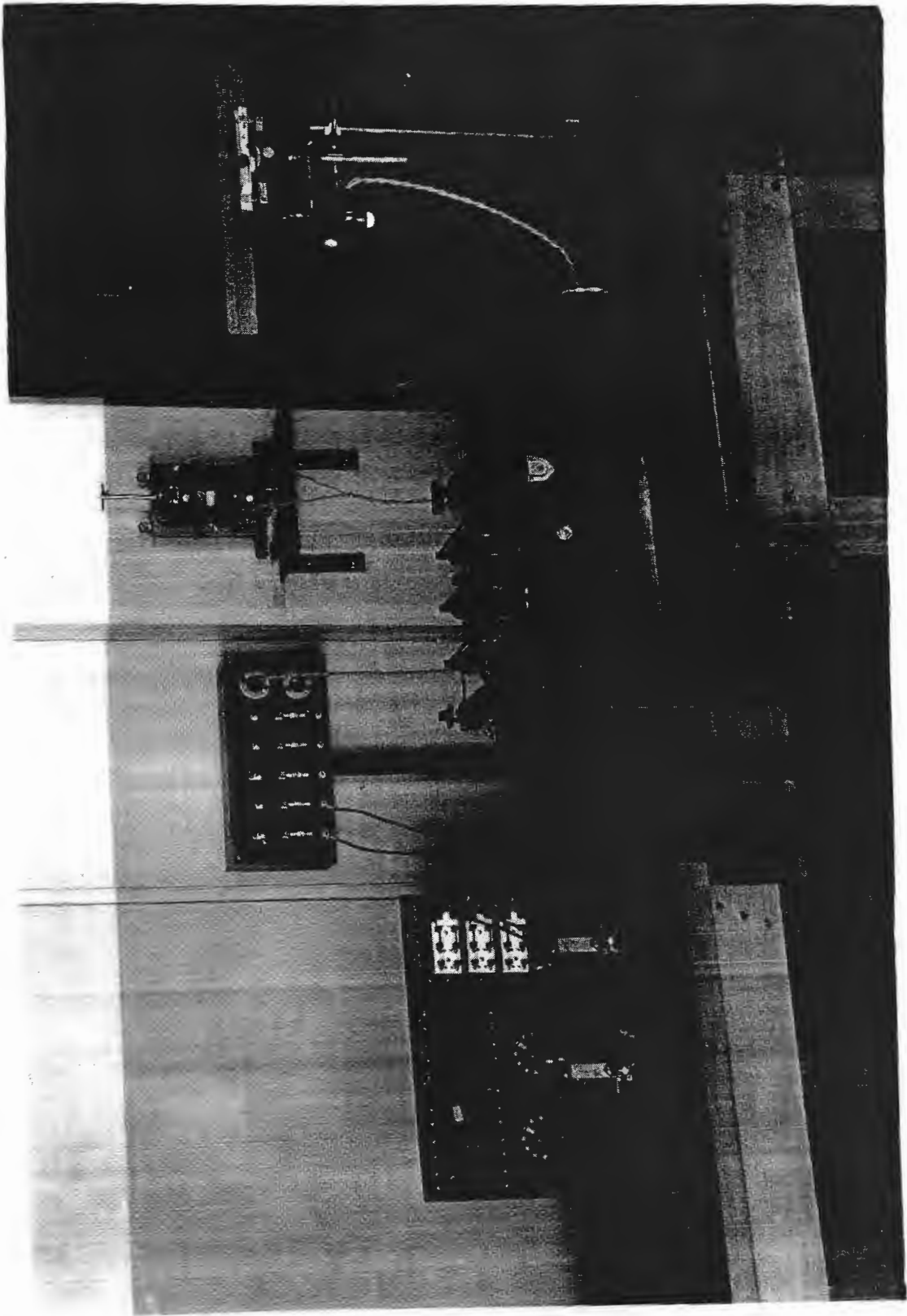


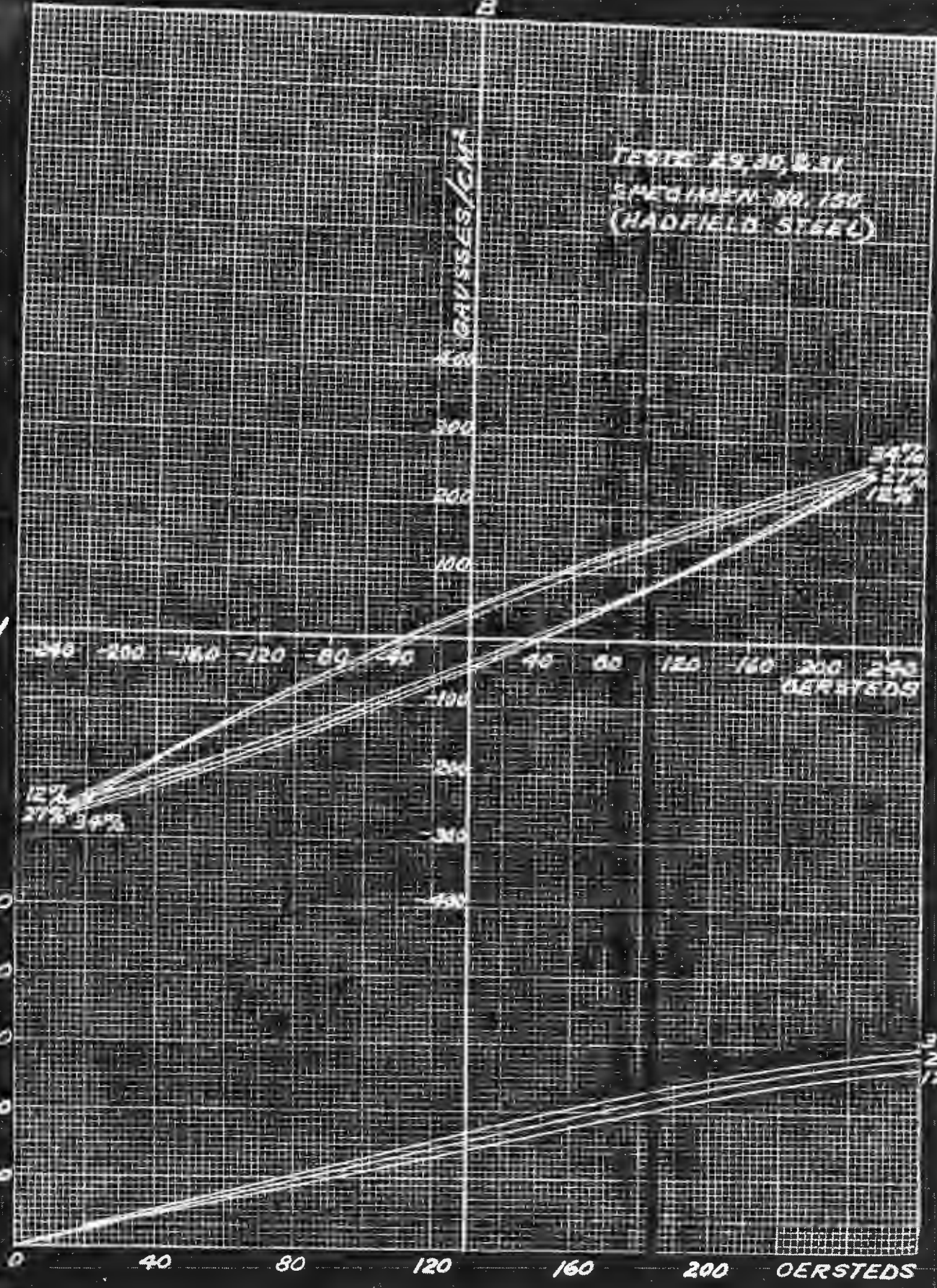
PLATE I

B

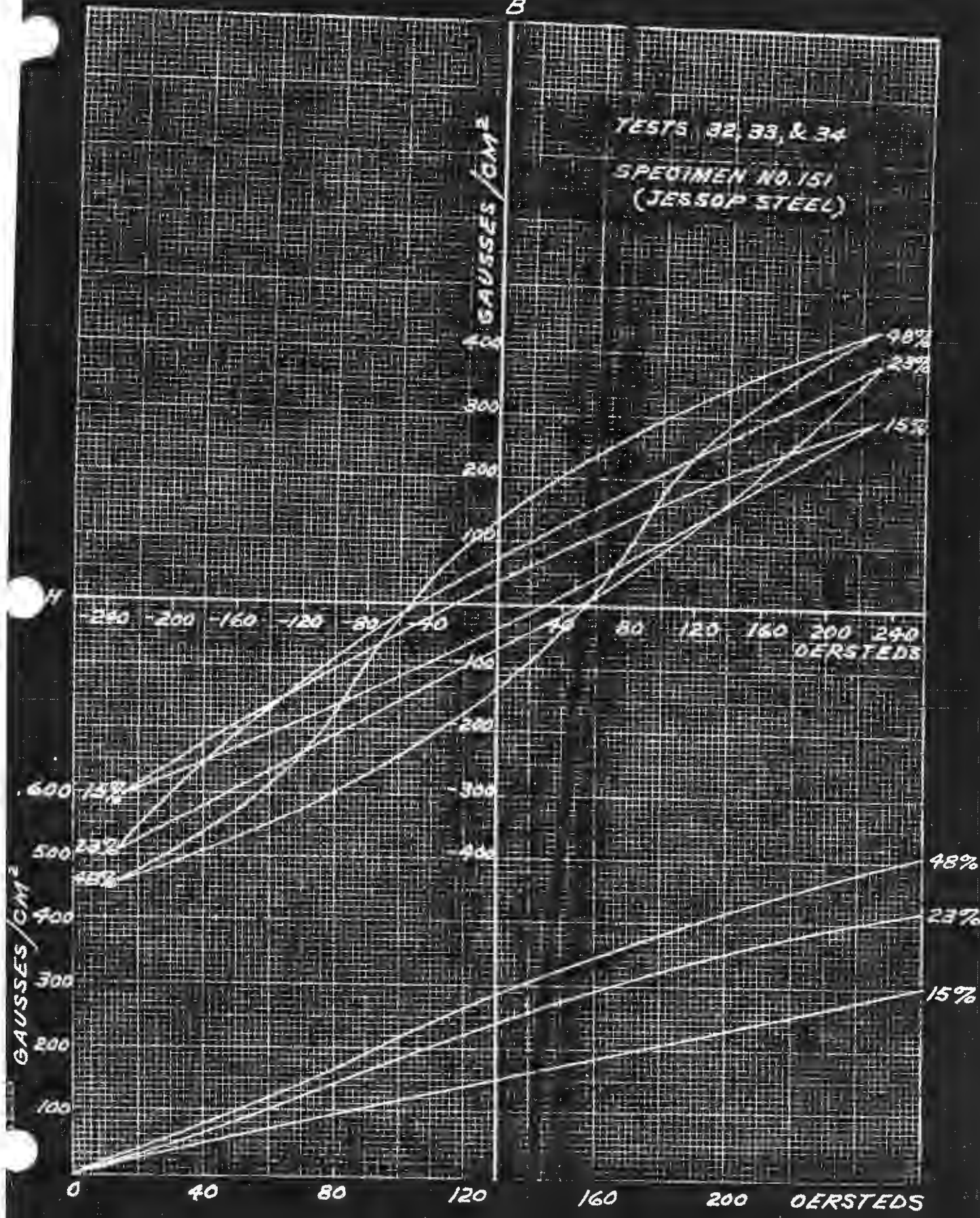
TESTS 29, 30, & 31
SPECIMEN NO. 130
(HADFIELD STEEL)

H

T.M.L.
GAUSSSES/CM

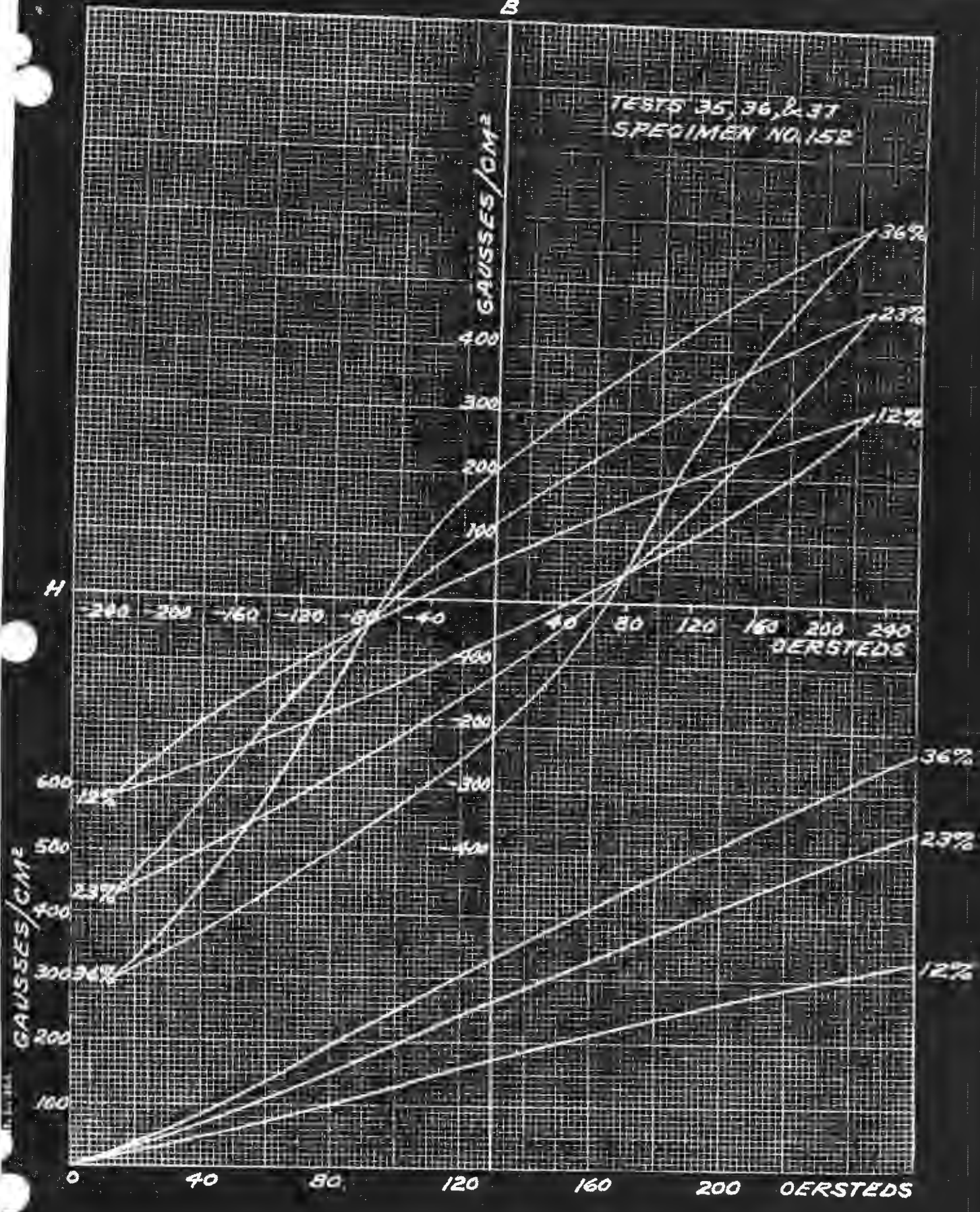


B

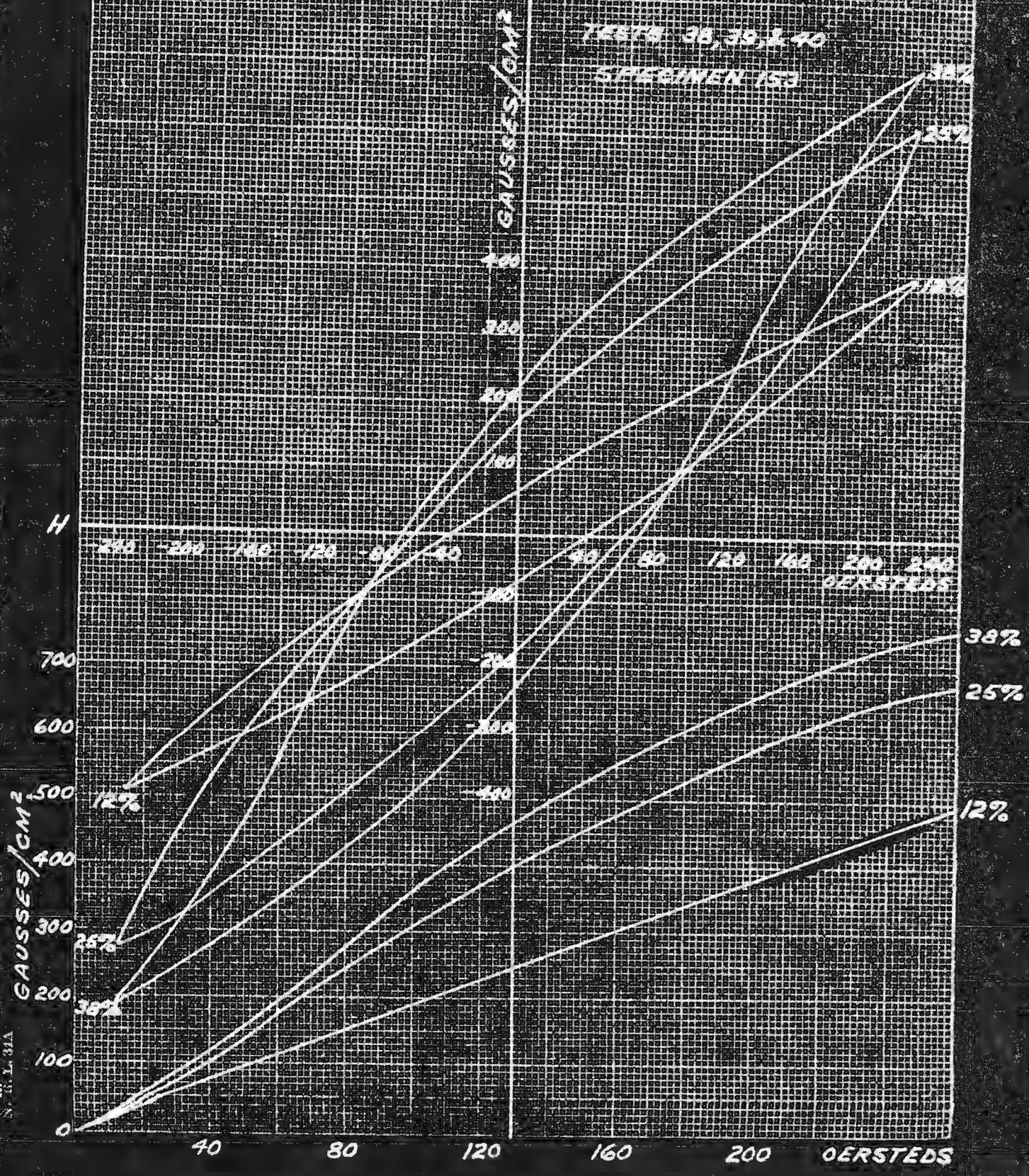


B

TESTS 35, 36, & 37
SPECIMEN NO. 152



B



R. L. 31A

TESTS 41, 42, & 43
 SPECIMEN NO. 754

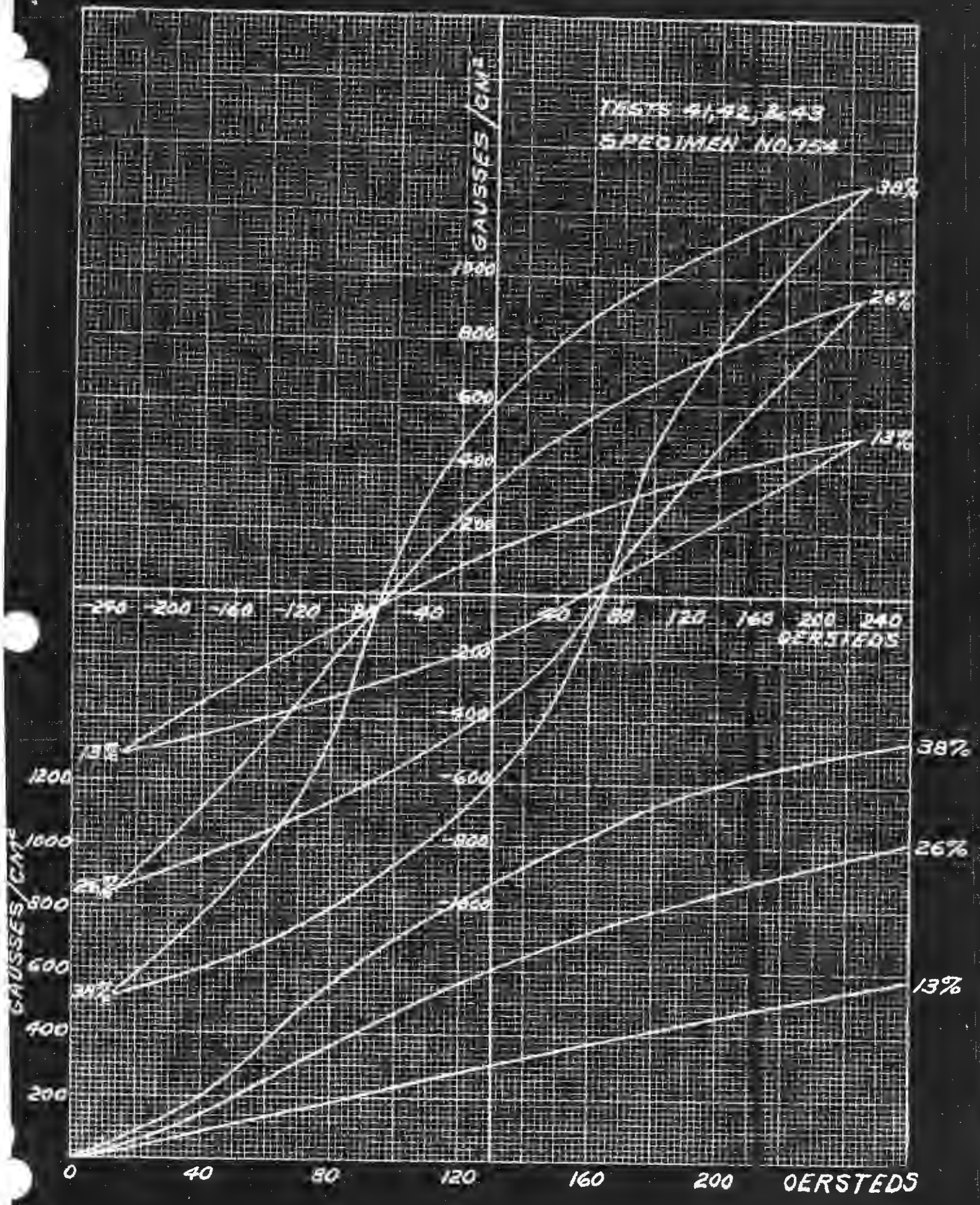
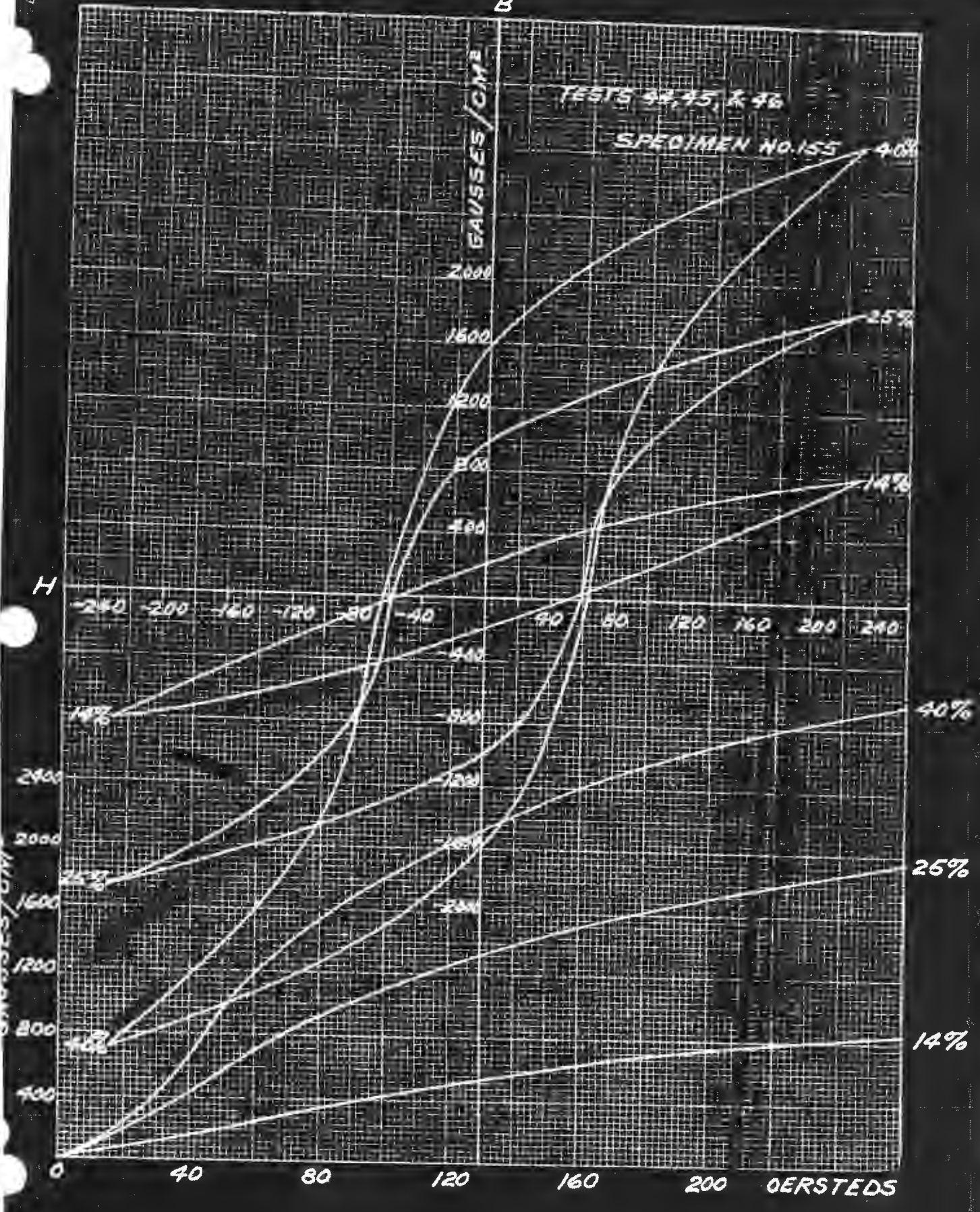


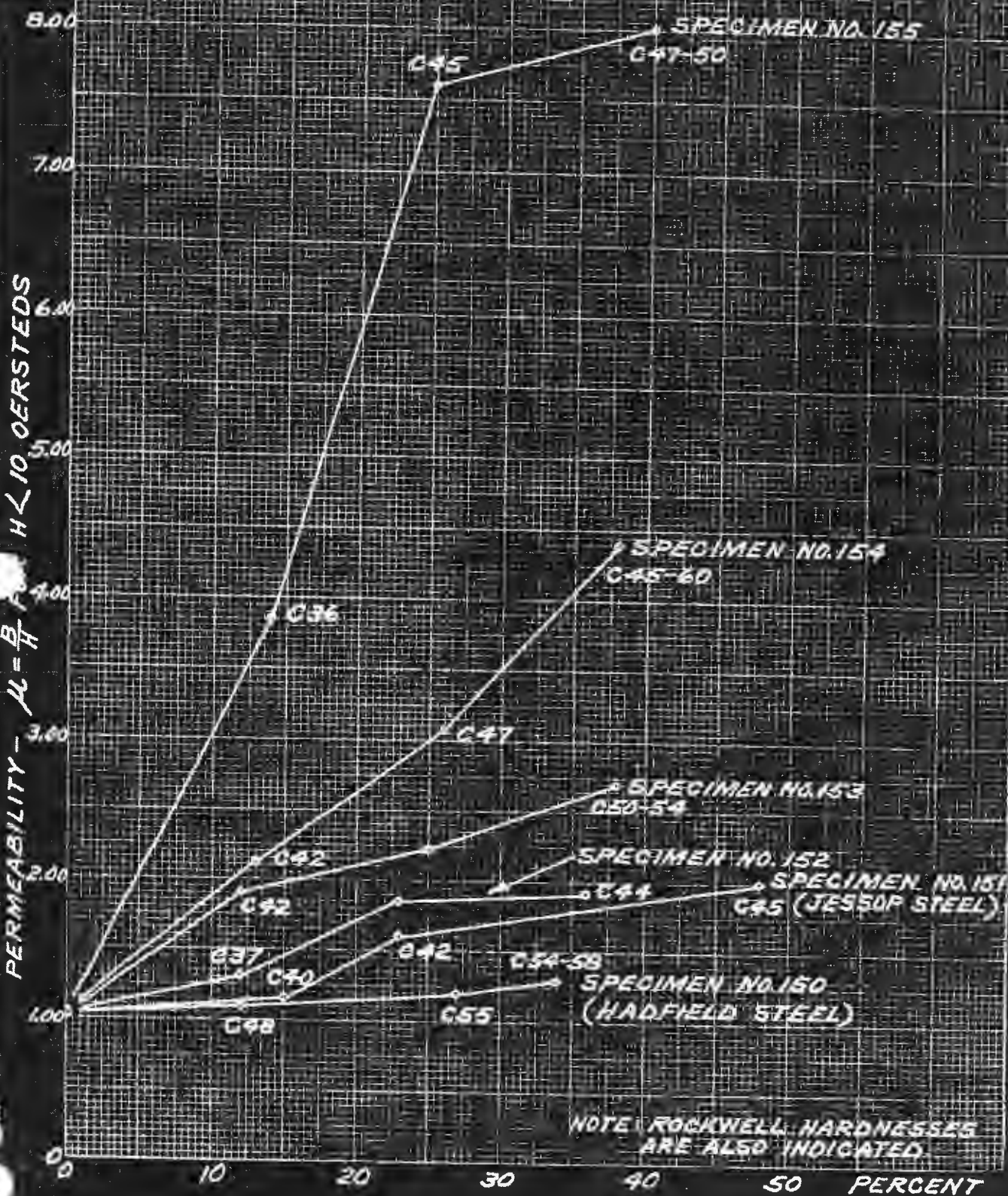
PLATE 6

B



H

PERMEABILITY - $\mu = \frac{B}{H}$



NOTE: ROCKWELL HARDNESSES ARE ALSO INDICATED

REDUCTION IN CROSS SECTION AREA BY COLD SWAGING

U. I. 34A

TABLE II

Summary of Results

Specimen No.	Test No.	%(1) Red.	Hardness (2)	A _i (H<10)	A _i Max.	B (H=260)	For H = 230 Oersteds			See Plate No.
							Er H _c	B _r x H _c	[BH]Max. k(3)	
150	29	12	C48	1.10	1.10	270	30	900	230	0.256
	30	27	C55	1.20	1.20	285	40	1440	360	0.250
	31	34	C54-58*	1.30	1.30	300	45	1710	440	0.257
151	32	15	C40	1.16	1.16	300	40	1120	280	0.250
	33	23	C42	1.60	1.85	420	70	3500	880	0.252
	34	48	C45	2.00	2.20	510	130	7020	1960	0.280
	35	12	C37	1.30	1.40	330	60	3000	750	0.250
152	36	23	--	1.85	2.10	540	120	7200	1800	0.250
	37	36	C44	1.92	2.60	670	210	14280	4370	0.306
	38	12	C42	1.90	1.90	490	70	2800	700	0.250
153	39	25	--	2.22	2.95	680	180	10800	2700	0.250
	40	38	C50-54*	2.70	3.60	760	220	15400	3960	0.257
154	41	13	C42	2.12	2.30	590	140	7640	1960	0.257
	42	26	C47	3.08	4.70	1020	360	23760	6460	0.272
	43	38	C45-60*	4.40	7.00	1350	580	40600	9880	0.244
155	44	14	C36	3.85	4.40	840	200	10800	2700	0.250
	45	25	C45	7.60	11.00	1960	1000	58000	14400	0.248
	46	40	C47-50*	8.00	20.00	2960	1600	102400	31680	0.308

(1) Percent reduction in cross-section area by cold swaging.

(2) Rockwell hardness numbers.

(3) A magnetic quality factor $k = \frac{[BH] \text{ max.}}{B_r \times H_c}$

* At these reductions, the surfaces were too brittle for accurate hardness measurements.