THE EFFECT OF VARIATION OF RULING SECTION ON THE MECHANICAL PROPERTIES OF CARBURIZING STEELS

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Abstract

Tensile and impact tests have been made on various carburizing steels heat-treated in sizes ranging from $\frac{1}{2}$ in. up to 4 in. diameter. The materials covered the older standard steels generally used in Britain, and the various standard 'substitute' steels which have been introduced because of alloy shortages, and a comparison has been made between them.

THE question of the effect of variation of ruling section on the core properties of carburizing steels is one which has only fairly recently come into prominence. While carburizing steels were used for components of only relatively small section, such as automobile gears and various shafting of diameter of the order of 1-$1\frac{1}{2}$ in., the conventional method of acceptance testing by using a bar of one fixed size, $1\frac{1}{8}$ in. in Britain and 30 mm. on the Continent, heat-treated according to the cycle which would be given to the final component, has been quite adequate.

However, two developments have made it desirable to have further data on the effect of size at the time of treatment on the properties of these steels. In the first place, carburizing steels are being used for various fairly large forgings in certain parts of the world, in particular for gears and pinions for large transmission installations, and the question of the properties of the main body of the forging as compared with those of the teeth, which are of much smaller relative section, has often arisen. Secondly, the universal shortage of nickel has made imperative the use of 'substitute' steels of lower nickel content but with similar properties to those they were designed to replace, as judged by the $1\frac{1}{8}$ in. bar test. However, users had developed considerable experience, of a somewhat empirical nature, of the earlier standard carburizing steels, and were able to estimate with fair shrewdness the suitability of one or another for any particular job. When they were suddenly ordered by the Government to use the substitute steels, on which they had no such experience, they not unnaturally required to be assured of the equivalence of the new steels with the old overall likely sizes, and whether there were, in fact, any limitations to the equivalence.

A short answer to this sort of question is given by the Jominy tests, but this is of only limited use since it gives a result only for the hardness, and hence the ultimate tensile strength of the material, whereas it is frequently the ductility and impact value which are called in question. Methods of deriving these have been suggested by various American workers[1], but they have been found to be very unreliable. Further, even the correlation, so popular in America, between hardness values from the Jominy test and from actual bars of various sizes, is considered in Britain to be of very doubtful validity, and very misleading results can be obtained from it[2]. Accordingly it was decided to perform a full investigation of the matter on full-size bars, covering the most important of the standard British carburizing steels as specified in the British Standards Institution Schedule 970 (1955), viz. En 34, En 36 and En 39 as representing the 'older' steels, and En 351 to En 355 inclusive, En 361, En 362 and

En 363, the substitute steels which replaced them.

These substitute steels were devised by the Alloy Steels (Rearmament) Technical Committee of Great Britain in 1951, when both nickel and molybdenum were in short supply. The series En 351 to En 355 are steels with minimum specified tensile strength in 1⅛ in. diameter bar double-quenched from 820° to 780°C., of 45, 55, 65, 75, 85 tons/sq. in. minima respectively, and the contents of nickel, chromium and molybdenum are successively raised to give these properties with carbon content below 0·20 per cent. However, in these steels the required ratio of nickel to molybdenum is of the order of 10:1 or higher, and this meant that in certain steelworks where a considerable amount of Ni-Cr-Mo scrap had to be used in which the nickel to molybdenum ratio was of the order of 6:1, raw nickel had to be added in their manufacture. Thus in certain instances the lower nickel contents were, in fact, a somewhat spurious economy, and did not take full advantage of the available scrap. To meet this difficulty the En 361, En 362 and En 363 series was also introduced. These will give minimum tensile strengths of 45, 55 and 65 tons/sq. in. respectively on 1⅛ in. diameter bar, but the nickel, chromium and molybdenum contents are fixed approximately in line with the usual nickel to molybdenum ratio available in scrap, while the increased tensile strength is obtained by raising the carbon content. The precise specifications of the En 361-363 steels were actually modelled on the American 8600 series since, apart from the convenience of the alloy ratios, there had been considerable satisfactory experience with these steels in the U.S.A. Inevitably with the rising carbon content the ductility and impact strength would fall, but it was felt that there was a large field of application in which this was immaterial.

The full specification of these steels is given in Table 1.

TABLE 1 — SPECIFICATIONS

All mechanical properties refer to test bars, blank carburized 880°-930°C., refined 850°-880°C. (air, oil or water-cooled), and hardened in oil from 870° to 820°C.

En No.	Analyses								Mech. Properties			Test bar size.
	C	Si	Mn	S	P	Ni	Cr	Mo	M.S. min.	El. min.	Izod min.	in.
34	0·14-0·20	0·10-0·35	0·30-0·60	0·05 max.	0·05 max.	1·50-2·00	—	0·20-0·30	45	18	40	1⅛
36A	0·15 max.	0·10-0·35	0·30-0·60	0·05 max.	0·05 max.	3·00-3·75	0·60-1·10	—	55	15	35	1⅛
36C	0·12-0·18	0·10-0·35	0·30-0·60	0·05 max.	0·05 max.	3·00-3·75	0·60-1·10	0·10-0·25	65	13	30	1⅛
39B	0·12-0·18	0·10-0·35	0·50 max.	0·05 max.	0·05 max.	3·80-4·50	1·00-1·40	0·15-0·35	85	12	25	0·6
351	0·20 max.	0·35 max.	0·60-1·00	0·05 max.	0·05 max.	0·60-1·00	0·40-0·80	0·10 max.	45	18	30	1⅛
352	0·20 max.	0·35 max.	0·50-1·00	0·05 max.	0·05 max.	0·85-1·25	0·60-1·00	0·10 max.	55	15	20	1⅛
353	0·20 max.	0·35 max.	0·50-1·00	0·05 max.	0·05 max.	1·00-1·50	0·75-1·25	0·08-0·15	65	12	20	1⅛
354	0·20 max.	0·35 max.	0·50-1·00	0·05 max.	0·05 max.	1·50-2·00	0·75-1·25	0·10-0·20	75	12	20	1⅛
355	0·20 max.	0·35 max.	0·40-0·70	0·05 max.	0·05 max.	1·80-2·20	1·40-1·70	0·15-0·25	85	12	25	0·6
361	0·13-0·17	0·35 max.	0·70-1·00	0·05 max.	0·05 max.	0·40-0·70	0·55-0·80	0·08-0·15	45	18	25	—
362	0·18-0·23	0·35 max.	0·70-1·00	0·05 max.	0·05 max.	0·40-0·70	0·55-0·80	0·08-0·15	55	15	15	—
363	0·22-0·26	0·35 max.	0·70-1·00	0·05 max.	0·05 max.	0·40-0·70	0·55-0·80	0·08-0·15	65	—	—	—

NOTE — M.S. = Maximum Tensile Stress. El. = Elongation per cent on a tensile specimen of 2 in. gauge-length and 0·564 in. diameter. Izod = ft.-lb. energy absorbed in the Izod impact test using the standard 10 mm. square specimen.

Materials and Preliminary Heat Treatment

The analyses and steel-making details of the steels used in this investigation are given in Table 2. They were hot-rolled from the ingot sizes shown, to produce 4¼ in. diameter billets. Some of these were then further rolled to produce various sizes down to ¾ in. diameter, and smaller sizes were machined from these ¾ in. diameter bars. All this material was given a normalizing treatment from 900°C. in order to refine the structures of the bars, and to bring them all into a reasonable degree of uniformity. This would also simulate the effect of the carburizing treatment which the steels would have if they were being put into service.

Effect of Reheating Temperature

The treatment called for in the specification, to be applied to the 1⅛ in. test bars, is a double-quenching operation. However, this is seldom or never used on production components, and B.S. 970, Appendix A, permits the single-quenching treatment (after cooling down from carburizing and removal from the box), this being a single reheat to 760°-800°C. and quenching, usually in oil. Some variants of this are occasionally applied, such as quenching straight 'from the box', or, if gas-carburizing is used, the steels may be cooled slowly in the furnace after carburizing at about 900°-930°C., and when a temperature of about 800°C. is reached, the whole charge is removed and quenched. Nevertheless, it was felt that the single reheat is fairly typical of most works' practice, and the properties were investigated after this treatment as well as after the full double-quench.

However, in order to check the optimum reheating temperature to develop the best core properties, certain casts were tested in 1⅛ in. diameter bar after reheating to various temperatures and oil-quenching. The results of these tests are shown graphically in Figs. 1-8.

It will be seen that, for all the steels, except En 353 and En 355, the single-quench temperature of 760°-800°C. given in B.S. 970, Appendix A, is too low, and that the reheat temperature should be at least 820°C. to develop the best combination of strength, ductility and impact properties. For En 353 and En 355 (and probably En 354, since its composition lies between these two) the minimum temperature is

TABLE 2—ANALYSES OF STEELS TESTED

En No.	Cast No.	C	Si	Mn	S	P	Ni	Cr	Mo	Grain Size
34	OD.5412	0·19	0·20	0·51	0·018	0·013	1·78	0·26	0·26	6-3
36A	HJ.1802	0·10	0·22	0·42	0·010	0·012	3·26	0·89	0·09	6-3
36C	HJ.2162	0·14	0·21	0·42	0·017	0·015	3·27	0·86	0·18	2-4
39B	HE.9434	0·16	0·22	0·38	0·014	0·018	4·28	1·41	0·23	7-6
351	OC.9837	0·15	0·24	0·83	0·032	0·024	0·76	0·67	0·06	7
352	HH.6587	0·13	0·23	0·90	0·017	0·019	1·08	0·90	0·11	8-4
353	OC.9923	0·20	0·19	0·97	0·010	0·018	1·34	1·00	0·10	8
354	HH.5963	0·21	0·19	0·81	0·015	0·017	1·96	1·07	0·19	7
355	HH.6575	0·17	0·30	0·59	0·013	0·010	2·02	1·78	0·19	5
361	OD.3158	0·13	0·27	0·81	0·016	0·030	0·60	0·61	0·10	7
362	OD.1512	0·21	0·21	0·87	0·015	0·018	0·64	0·67	0·13	6
363	OD.1518	0·25	0·32	0·72	0·013	0·022	0·64	0·67	0·13	7

All steels were made in the basic electric arc furnace, and the ingot sizes of the above casts were approximately 15¼ in. sq. (top end), with the exception of En 34 which was 17¼ in. sq.

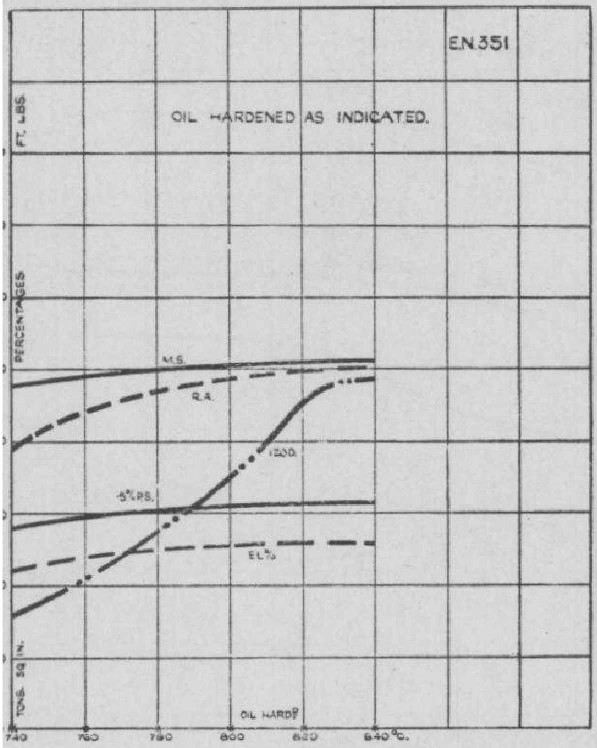


FIG. 1

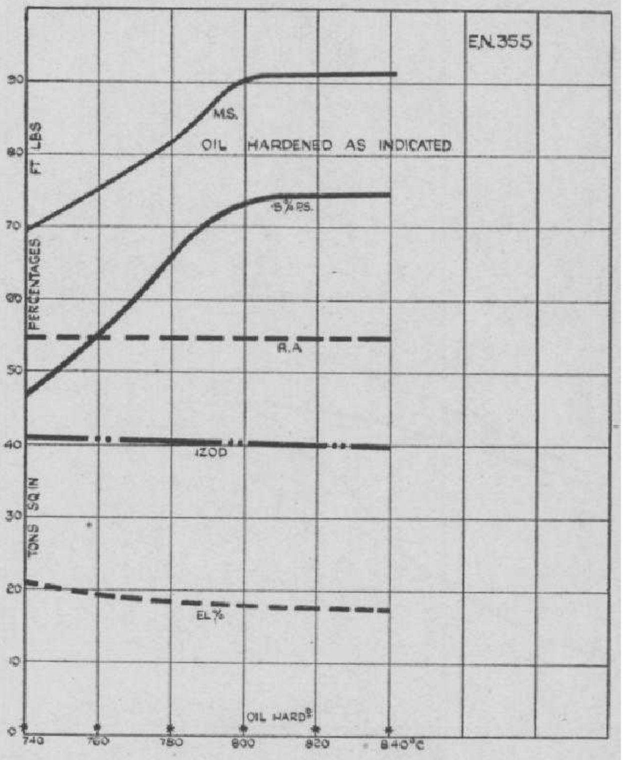


FIG. 3

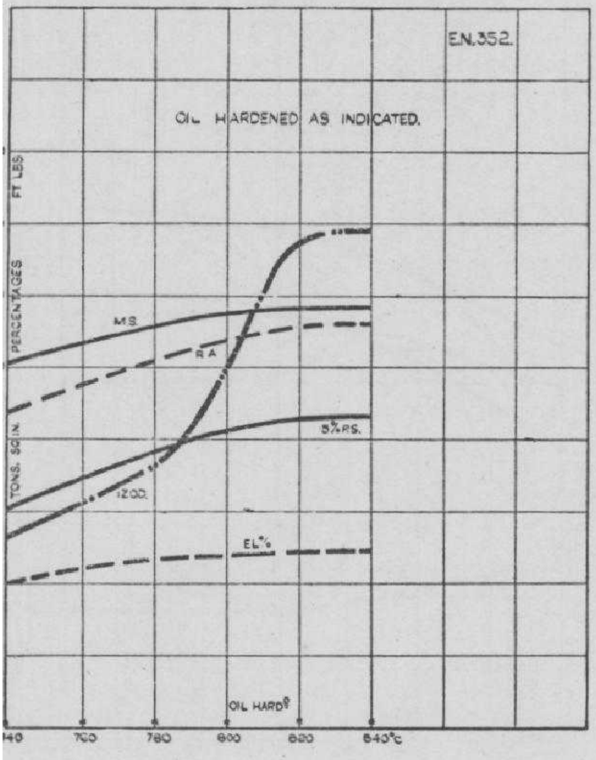


FIG. 2

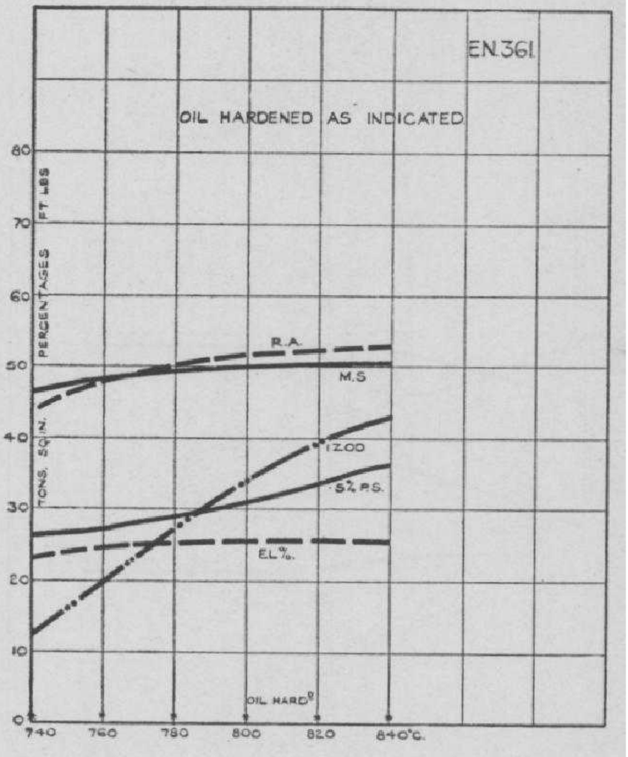


FIG. 4

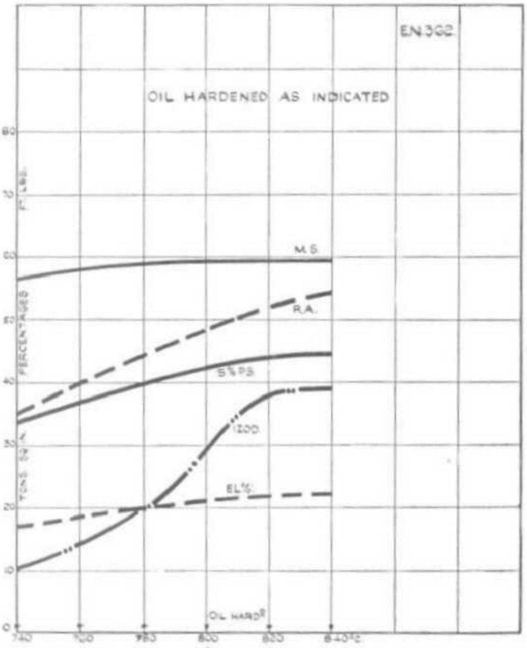


FIG. 5

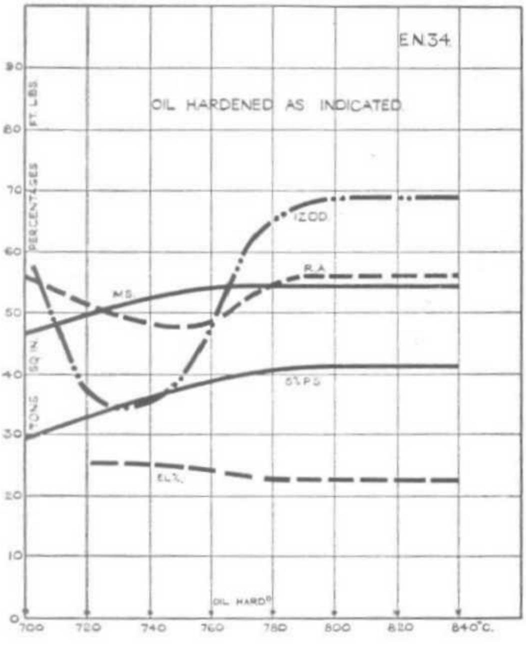


FIG. 6

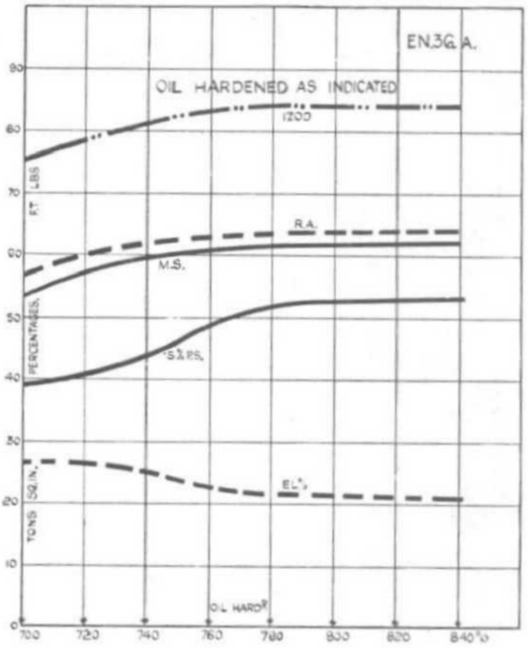


FIG. 7

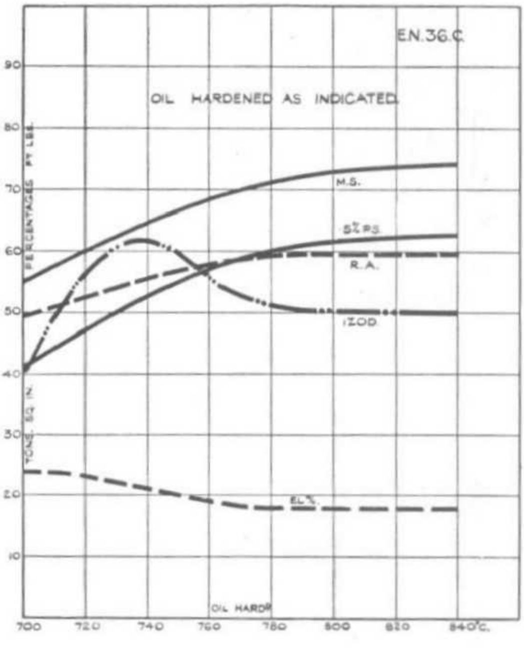


FIG. 8

800°C. For the very low alloy steels, En 351, En 361 and 362, 840°C. would not be too high, although if these temperatures were unduly exceeded, there may be some danger of grain growth in the case material. In view of the above results, the reheating temperature used for the single-quench treatment was 820°C. for all the steels.

Tests on Various Sizes of Bar

Each of the steels tested in Table 2 were heat-treated in sizes from ½ to 4 in., except for En 34 where the largest size was 3 in. For bars up to 1⅛ in. diameter, the tensile and Izod testpieces were cut axially; for bars over 1⅛ in. and up to and including 3 in., the axes of the testpieces were taken midway between the centre and surface of the bars.

The results of the tests on the double-quenched bars are given in Tables 3, 4 and 5, and those on the single-quenched bars in Tables 6, 7 and 8. These results are shown graphically in Figs. 9-31.

Discussion of Results

The least 'mass effect', as judged by the variation in tensile strength between ½ in. bars and 4 in. bars, is shown by the lowest alloy steels, En 351, En 352 and En 361.

TABLE 3

All bars air-cooled 900°C.; *refined* 860°C.; *hardened* 780°C., *except* 34 *which were hardened* 800°C.

En No.	Bar diam., in.	LP	P.S.		M.S.	El. %	R.A. %	Izod
			0·1%	0·5%				
	0·424	23	46·6	65·8	71·4	17·8	51·6	48-51-49
	¾	16	34·0	44·7	56·1	21·5	56·9	58-65-61
34	1	18	30·6	42·5	52·0	24·5	60·4	66-73-74
OD.5412	1⅛	14	33·0	44·0	54·2	21·0	56·6	67-71-72
	2⅛	14	29·6	36·0	47·2	27·1	67·0	104-105-104
Fig. 9	3	15	28·0	34·0	45·4	28·2	66·0	104-113-113
	0·424	19	46·4	70·9	75·1	20·0	63·8	68-67-63
	¾	27	45·6	60·6	66·9	20·1	61·5	77-82-84
36A	1	15	36·3	49·9	62·4	23·3	64·0	91-90-91
	1⅛	15	35·8	51·4	61·3	22·0	63·6	82-82-82
HJ.1802	2⅛	11	30·1	42·5	55·3	25·0	64·0	103-104-107
	3	19	31·3	40·2	54·3	24·9	62·2	107-107-107
Fig. 10	4	17	29·9	38·2	52·7	26·0	64·8	105-106-106
	0·424	21	48·5	70·9	82·5	20·0	66·7	47-47-49
	¾	17	47·0	67·5	80·6	17·0	59·2	51-49-49
36C	1	21	45·1	62·9	75·6	18·0	59·4	56-55-59
	1⅛	16	42·1	60·0	72·2	19·0	59·2	58-56-58
HJ.2162	2⅛	17	37·9	54·2	62·7	19·0	63·0	65-66-69
	3	22	34·3	50·4	59·7	22·3	61·1	71-70-76
Fig. 11	4	20	35·1	46·2	59·7	24·0	58·5	67-66-68
	0·564	25	50·5	72·0	89·4	17·3	54·4	34-34-32
	¾	—	—	—	88·0	15·7	56·1	37-34-36
39B	1⅛	27	55·5	71·9	85·7	17·8	58·5	39-40-39
	2⅛	24	48·6	64·2	78·2	17·3	59·9	49-54-51
HE.9434	3½	24	43·5	59·0	74·0	19·9	59·9	60-63-62

TABLE 4

All bars air-cooled 900°C.; refined 860°C., oil; hardened 800°C., oil

En No.	Bar diam., in.	LP	P.S.		M.S.	El. %	R.A. %	Izod
			0·1%	0·5%				
	0·424	7	22·9	32·4	55·7	22·0	44·9	46-47-48
	¾	11	21·5	29·8	51·3	28·0	52·2	52-53-60
351	1	10	21·9	28·0	49·4	28·6	54·5	59-59-58
	1⅛	13	21·9	28·2	49·5	29·2	55·3	62-61-63
OD.9837	2⅛	11	20·4	26·4	46·6	29·8	61·3	75-68-76
	3	12	20·8	28·7	45·5	30·6	61·5	89-68-62
Fig. 13	4¼	10	19·0	25·8	44·1	30·1	61·3	79-75-71
	0·424	16	36·6	52·5	64·1	17·5	51·9	56-50-49
	¾	13	31·7	45·0	60·5	20·8	52·3	61-62-62
325	1	14	29·1	40·6	57·1	23·9	54·1	60-68-67
	1⅛	14	28·3	37·9	54·7	24·4	55·1	70-73-78
HH.6587	2⅛	14	24·7	33·9	52·5	26·0	54·8	72-68-69
	3	12	23·3	32·2	50·6	27·0	54·4	65-64-64
Fig. 14	4¼	12	21·5	28·6	49·4	28·4	54·4	87-55-61
	0·424	23	51·8	78·9	95·9	16·1	55·8	33-32-30
	¾	25	54·2	71·6	85·2	14·0	47·9	33-29-30
353	1	27	52·7	66·4	78·6	17·9	56·2	38-36-37
	1⅛	25	51·0	63·5	74·2	16·8	56·5	46-45-40
OC.9923	2⅛	19	41·4	52·9	67·8	21·5	52·9	44-40-45
	3	18	42·1	49·3	66·3	20·2	49·2	54-48-50
Fig. 15	4¼	13	32·5	43·6	63·8	23·8	53·6	38-33-34
	0·424	12	51·1	77·7	99·4	16·5	52·6	29-30-28
	¾	28	60·0	81·7	97·4	16·2	52·2	29-28-28
354	1	39	65·2	82·2	94·6	16·1	53·9	31-30-30
	1⅛	41	66·0	80·2	90·5	15·3	55·6	33-30-25
HH.5963	2⅛	26	49·7	64·8	78·7	26·5	53·2	32-43-31
	3	22	47·8	59·8	76·1	18·5	49·2	35-45-47
Fig. 16	4¼	16	39·4	54·5	68·4	19·0	56·9	27-30-34
	0·424	17	52·5	75·3	93·8	17·0	53·2	39-37-38
	¾	19	52·2	74·9	93·4	16·7	52·4	35-37-39
355	1	23	51·3	74·5	90·8	16·0	54·4	39-38-38
	1⅛	27	55·7	73·5	88·1	17·5	56·1	43-41-40
HH.6575	2⅛	26	51·7	66·9	77·4	18·2	60·2	47-49-51
	3	27	50·6	64·1	76·5	20·0	56·9	60-60-65
Fig. 17	4¼	27	47·0	60·7	73·0	19·0	56·2	61-60-65

For these steels the hardenability is so low that the structures are predominantly pearlite and upper bainite over the whole of this range of size.

The other steels, of greater hardenability, are such that considerable variation of structure can occur over the size-range considered, although the actual amount of change of the tensile value varies according to the relative change of constitution over the full size-range.

The ductility (elongation per cent) generally follows the course one would expect in view of the tensile change, the diminishing

TABLE 5

All bars air-cooled 900°C.; refined 860°C., oil; hardened 800°C., oil

En No.	Bar diam., in.	LP	P.S.		M.S.	El. %	R.A. %	Izod
			0·1%	0·5%				
	0·424	10	26·1	38·9	52·3	26·7	55·1	60-60-62
	¾	10	21·1	30·4	50·8	28·5	54·4	56-60-64
361	1	12	22·3	30·0	49·0	28·9	56·7	60-62-64
	1⅛	13	22·0	29·6	48·6	31·1	57·8	59-66-75
OD.3158	2⅛	12	22·4	33·5	46·0	24·5	54·6	67-59-65
	3	11	22·7	27·6	44·9	31·2	57·1	56-54-50
Fig. 18	4¼	11	20·0	29·0	43·8	31·8	57·8	44-48-52
	0·424	7	31·5	48·3	66·7	18·0	44·8	25-26-25
	¾	10	35·0	48·7	65·5	19·0	44·0	32-36-35
362	1	19	35·2	47·3	60·2	22·9	56·9	35-32-34
	1⅛	15	33·0	45·5	60·0	21·0	50·7	38-32-35
OD.1512	2⅛	7	23·6	32·6	53·1	25·0	50·9	31-36-45
	3	9	22·7	33·4	51·4	25·9	50·4	35-35-35
Fig. 19	4¼	8	22·2	31·6	48·5	27·8	55·2	36-35-35
	0·424	14	41·0	63·9	80·9	12·8	35·7	23-22-21
	¾	17	36·8	51·0	66·7	18·7	42·4	28-30-30
363	1	20	36·7	48·5	63·8	21·1	45·3	30-32-30
	1⅛	17	35·5	45·3	60·5	21·2	45·0	26-27-27
OD.1518	2⅛	12	25·8	36·3	56·4	20·6	43·0	36-31-34
	3	12	25·0	36·1	53·6	22·9	43·0	32-27-26
Fig. 20	4¼	12	24·8	34·9	53·7	23·5	44·5	31-32-31

TABLE 6

All bars air-cooled 900°C.; hardened 820°C., oil

En No.	Bar diam., in.	LP	P.S.		M.S.	El. %	R.A. %	Izod
			0·1%	0·5%				
	0·424	25	45·7	61·3	70·7	14·6	53·5	48-50-47
34	¾	16	34·0	44·7	55·9	21·8	56·0	58-60-60
	1	20	32·0	43·0	53·0	25·0	58·1	65-70-67
OD.5412	1⅛	19	33·1	43·6	54·0	20·8	56·5	65-74-73
	2⅛	16	28·4	35·2	46·5	28·6	67·0	90-98-102
Fig. 21	3	15	28·2	34·4	45·8	26·1	64·5	106-113-108
	0·424	21	55·1	74·4	75·3	18·0	62·4	64-68-70
	¾	13	41·5	57·8	69·6	19·0	61·1	72-72-73
36A	1	14	36·6	51·9	61·6	20·0	63·0	83-85-83
	1¼	12	36·5	52·0	62·7	21·0	61·7	82-82-80
HJ.1802	2⅛	15	32·5	45·3	54·7	23·0	67·4	101-104-106
	3	20	33·0	41·5	54·2	25·6	63·6	109-108-105
Fig. 22	4	20	32·4	40·2	51·5	25·1	67·0	111-111-112
	0·424	21	49·9	73·6	82·1	16·2	57·8	46-46-47
	¾	13	44·6	68·6	79·6	19·0	51·8	40-40-46
36C	1	13	42·9	62·9	76·0	17·0	59·2	54-50-50
	1⅛	17	46·0	61·8	73·3	16·0	50·3	53-51-50
HJ.2162	2⅛	18	37·5	53·4	63·3	19·0	63·1	58-72-55
	3	18	35·0	50·5	60·8	21·5	60·2	54-55-58
Fig. 23	4	18	38·5	54·3	60·4	21·7	62·2	45-51-50

TABLE 7

All bars air-cooled 900°C.; *hardened* 820°C., *oil*

En No.	Bar diam., in.	LP	P.S.		M.S.	El. %	R.A. %	Izod
			0·1%	0·5%				
	0·424	9	27·5	40·1	59·0	21·0	47·2	36-36-32
	¾	10	22·5	32·5	52·8	24·6	45·8	42-40-50
351	1	12	23·2	31·6	51·4	25·5	50·9	41-42-39
	1⅛	10	22·2	30·1	50·9	29·0	50·7	44-47-52
OD.9837	2⅛	10	20·6	28·0	45·4	29·9	58·8	56-50-57
	3	11	20·6	26·2	43·6	30·0	59·2	58-58-58
Fig. 24	4¼	10	18·2	24·0	42·0	31·0	59·2	62-55-64
	0·424	16	36·8	51·6	63·7	20·6	59·4	61-61-57
	¾	16	33·6	45·4	58·3	22·2	57·8	64-65-67
352	1	18	32·7	42·6	56·3	22·0	40·2	66-69-67
	1⅛	17	30·8	40·6	55·0	23·9	56·7	62-64
HH.6587	2⅛	15	27·4	36·1	52·0	25·0	54·6	69-71-74
	3	12	24·3	33·7	51·0	25·6	54·1	65-61-60
Fig. 25	4¼	12	23·6	31·5	49·2	28·1	52·2	65-56-67
	0·424	21	55·8	78·1	94·1	16·6	52·9	29-30-30
	¾	38	59·2	72·9	85·2	15·8	51·6	35-32-34
353	1	23	51·5	64·1	78·8	20·6	57·6	35-35-35
	1⅛	25	45·7	60·5	75·4	16·9	50·9	36-40-40
OC.9923	2⅛	17	36·6	50·4	66·9	19·6	47·4	48-51-51
	3	23	40·5	50·0	64·2	22·0	54·6	49-42-43
Fig. 26	4¼	8	33·3	49·2	64·7	22·0	47·1	48-42-45
	0·424	24	57·4	80·2	98·9	16·6	52·6	34-30-27
	¾	29	60·5	82·1	98·4	16·4	51·4	22-26-28
354	1	42	69·3	84·5	94·9	15·3	55·6	22-28-29
	1⅛	44	69·0	83·0	91·7	16·0	55·8	30-31-26
HH.5963	2⅛	18	48·5	65·0	78·8	16·2	52·2	24-36-39
	3	21	44·2	59·5	73·8	19·5	51·1	44-39-41
Fig. 27	4¼	24	46·4	62·6	70·7	19·0	61·5	36-36-37
	0·424	21	52·7	78·2	91·7	17·0	53·5	35-40-39
	¾	25	52·2	74·9	91·3	16·0	55·8	36-34-34
355	1	22	51·0	74·2	90·2	16·9	56·5	35-41-39
	1⅛	31	58·0	76·3	90·7	17·3	56·0	43-42-40
HH.6575	2⅛	24	52·4	68·0	80·0	17·2	57·8	58-55-56
	3	24	46·6	61·9	76·7	19·0	56·9	59-56-59
Fig. 28	4¼	27	46·9	60·6	74·0	19·7	57·8	59-55-57

tensile strength as size increases being associated with increasing (or at least non-diminishing) elongation per cent.

It is interesting, however, to note that on the tests of the effect of quenching temperature, the maximum stress and elongation generally rise together as the temperature is lifted, reflecting presumably the effect of a greater degree of solution of the ferrite in the austenite.

However, the variation of Izod presents some interesting results. This figure either rises continually as the size increases (e.g. En 34, 351, 354 and 355, double-quenched)

TABLE 8

All bars air-cooled 900°C.; *hardened* 820°C., *oil*

En No.	Bar diam., in.	LP	P.S.		M.S.	El. %	R.A. %	Izod
			0·1%	0·5%				
	0·424	15	33·3	45·4	56·6	23·6	60·3	49-51-49
	¾	15	28·0	39·4	54·4	24·0	52·2	45-43-44
361	1	12	26·1	35·9	52·5	24·8	53·4	36-36-43
	1⅛	15	26·1	35·4	51·1	26·0	54·1	43-39-44
OD.3158	2⅛	10	20·1	30·4	45·5	26·2	54·4	30-28-32
	3	13	23·4	35·0	44·9	28·8	55·1	35-30-31
Fig. 29	4	10	19·0	29·4	43·3	31·0	52·7	33-27-28
	0·424	9	36·8	56·9	69·0	18·0	53·2	32-30-28
	¾	12	35·9	51·5	65·1	19·3	50·9	39-36-41
362	1	14	32·9	46·4	60·4	22·0	49·7	46-42-47
	1⅛	17	34·5	45·0	58·5	22·6	54·1	35-47-49
OD.1512	2⅛	8	28·0	39·0	52·4	28·1	56·2	39-37-36
	3	8	28·4	36·0	50·2	25·0	54·1	47-45-44
Fig. 30	4	8	23·0	35·0	47·9	24·9	55·8	49-56-45
	0·424	26	48·0	64·7	76·8	15·2	42·3	24-25-24
	¾	18	37·6	52·4	70·0	17·0	45·0	25-27-29
363	1	16	35·0	47·0	62·7	19·9	45·0	30-33-30
	1⅛	22	36·0	48·7	62·5	22·8	49·7	30-32-31
OD.1518	2⅛	13	28·4	39·1	54·8	21·4	46·8	31-34-30
	3	11	25·4	35·4	52·8	22·6	45·0	32-34-30
Fig. 31	4¼	16	27·8	36·7	52·5	24·0	47·6	34-31-29

or rises to a maximum and then falls (e.g. En 352 and 353, double-quench). Such behaviour has been observed before, for example, in Section VIA of the Hardenability Symposium[2] many instances are given where the Izod value first rises as the as-quenched hardness falls from the fully martensitic condition, and, after passing over a maximum, decreases as the as-quenched hardness falls further with increasing ' slackness ' of quenching.

Comparison of Newer and Older Steels

(a) Forty-five tons/sq. in. minimum tensile level, En 34, 351, 361. The newer steels En 351, 361, have generally less ' mass effect ' than the older, though the Izod level is lower. The new steels are rather more sensitive to the difference in heat treatment between double and single-quench.

(b) Fifty-five tons/sq. in. minimum tensile level, En 36A, 352, 362. En 352 shows less mass effect on tensile strength than En 36A, but En 362 is almost identical with it. En 362 is rather lower in impact value than the other two, but is nevertheless quite adequate. It is also rather more sensitive to the heat treatment difference than the other two.

(c) Sixty-five tons/sq. in. minimum tensile level, En 36C, 353, 363. The tensile values of all three steels have about the same mass effect. Again, En 363 has lowest impact, but still quite adequate for all purposes. None of the steels are particularly sensitive to the differrence in treatment.

(d) Seventy-five tons/sq. in. minimum tensile level, En 354 only. This has a well-marked mass effect, rather more pronounced than En 36, the tensile falling by nearly 20 tons/sq. in. between 1⅛ and 4 in.

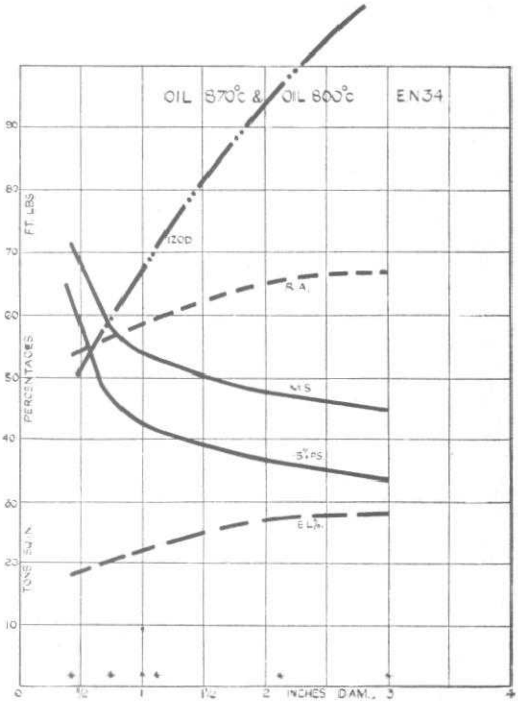
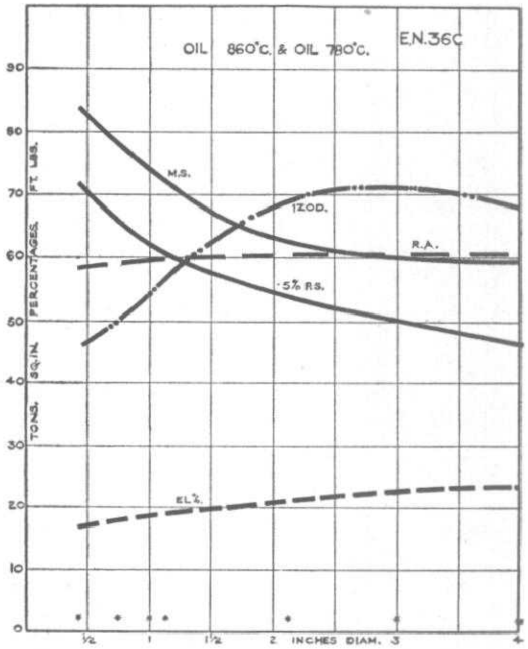


FIG. 9



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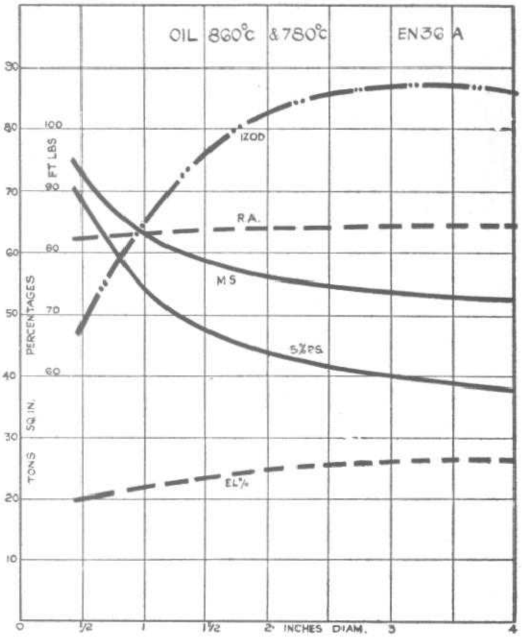

FIG. 10

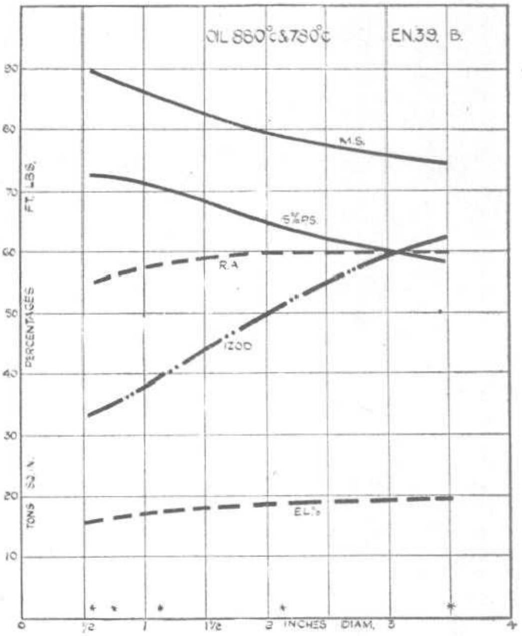

FIG. 12

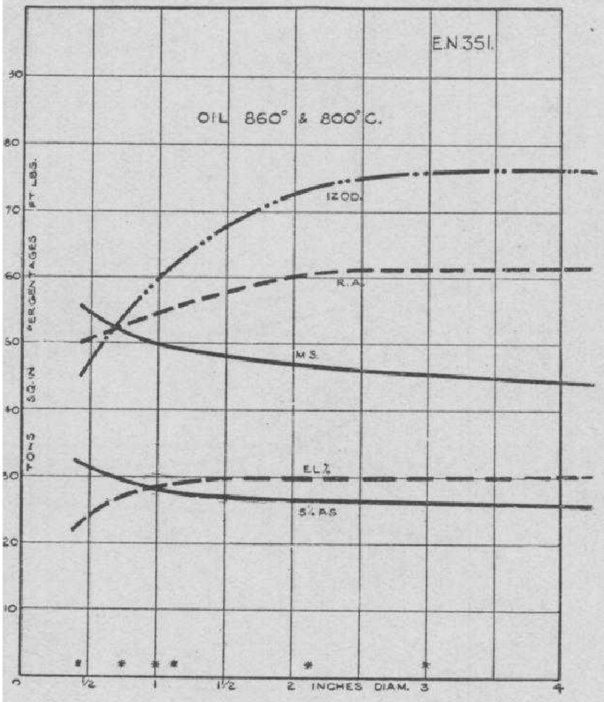

FIG. 13

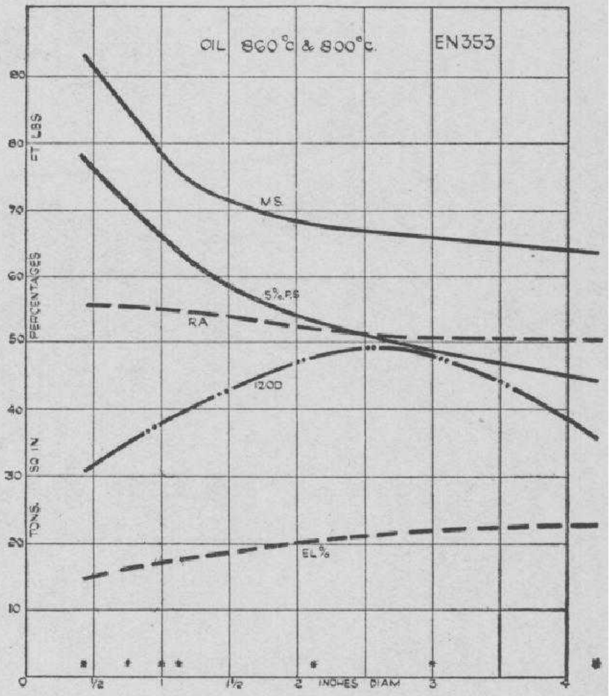

FIG. 15

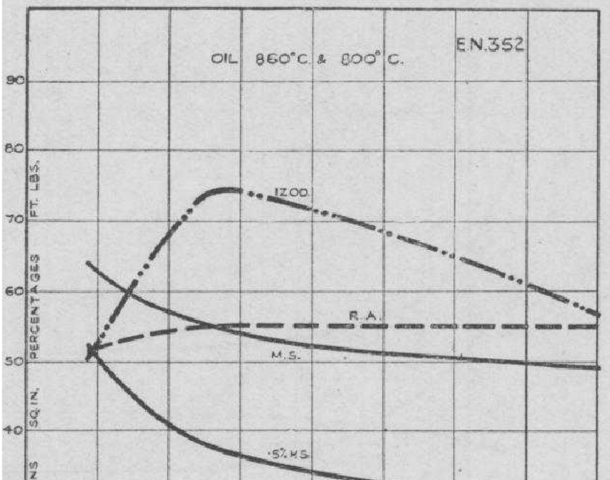

FIG. 14

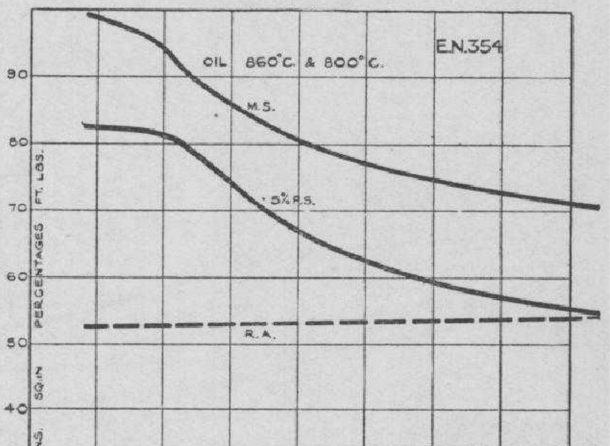

FIG. 16

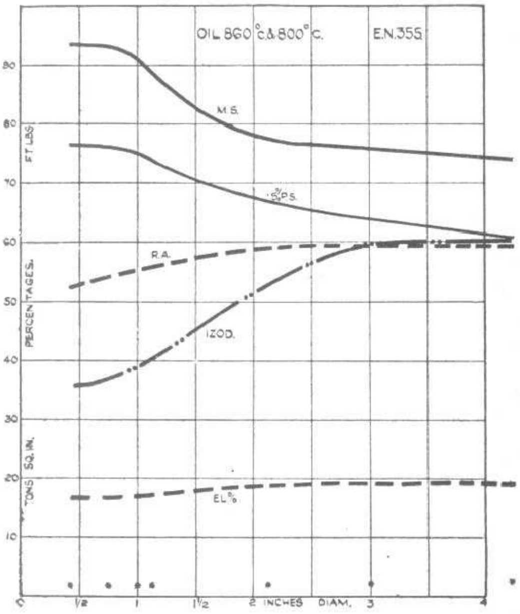

FIG. 17

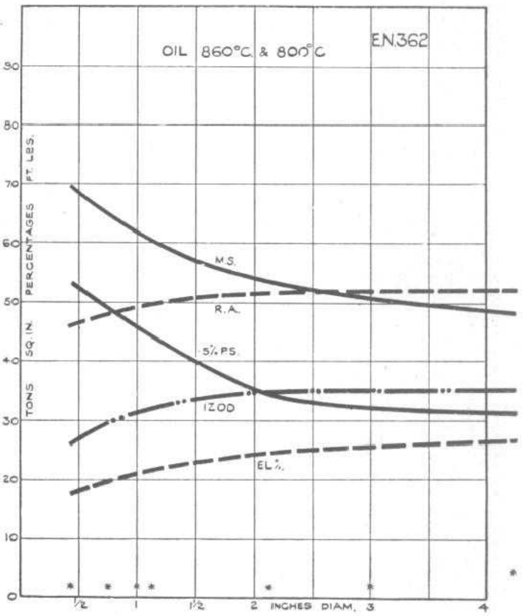

FIG. 19

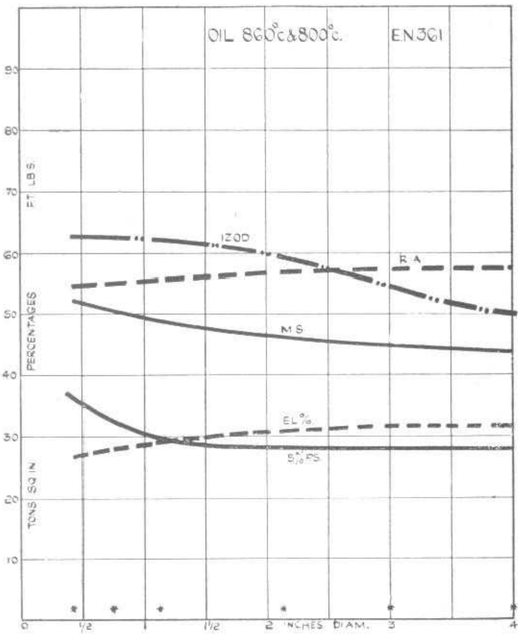

FIG. 18

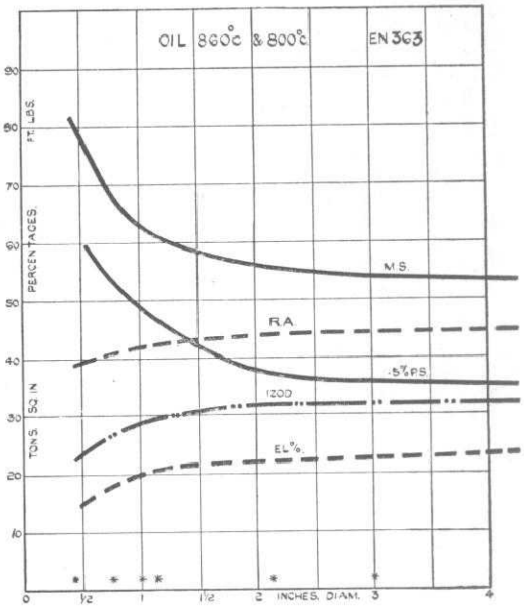

FIG. 20

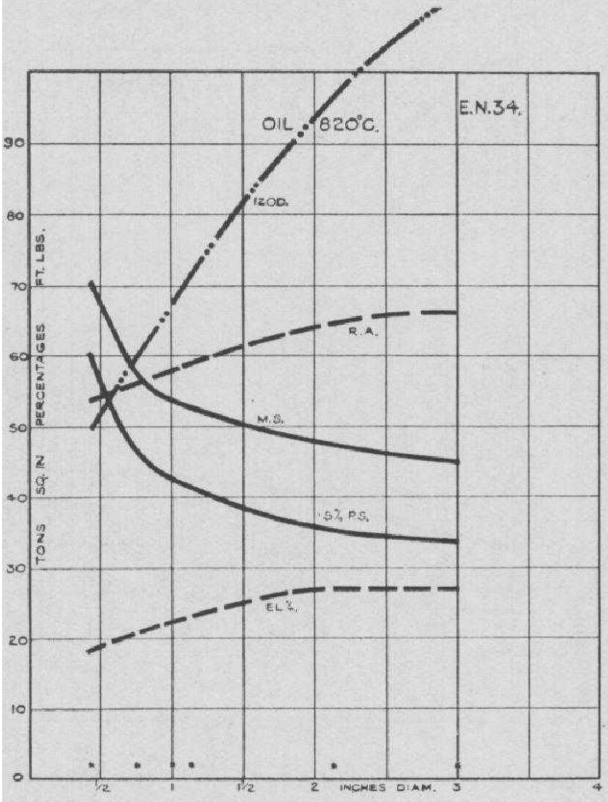

FIG. 21

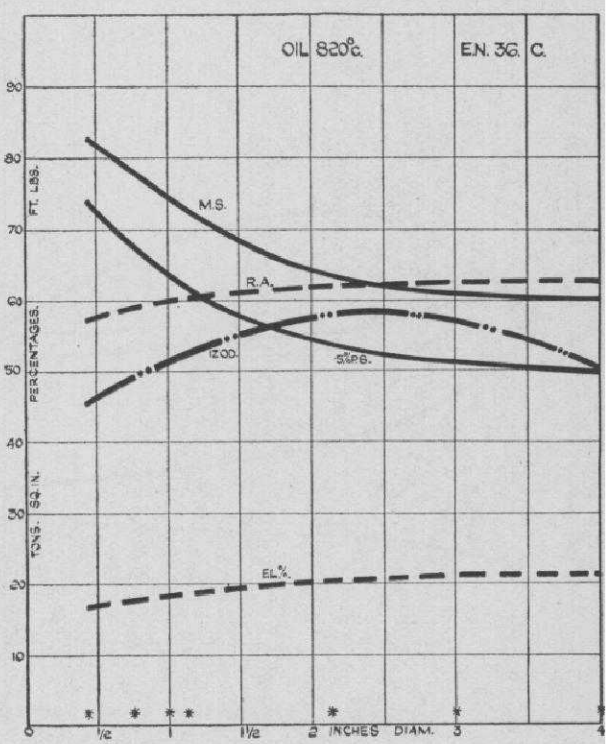

FIG. 23

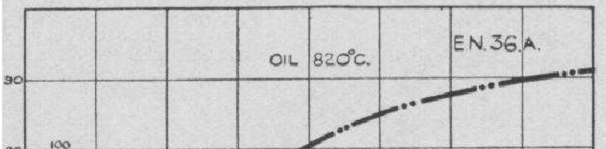

FIG. 22

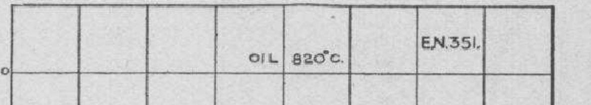

FIG. 24

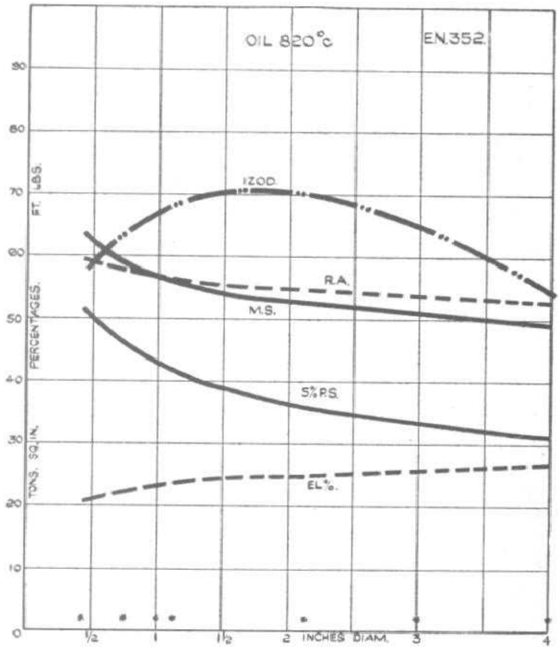

FIG. 25

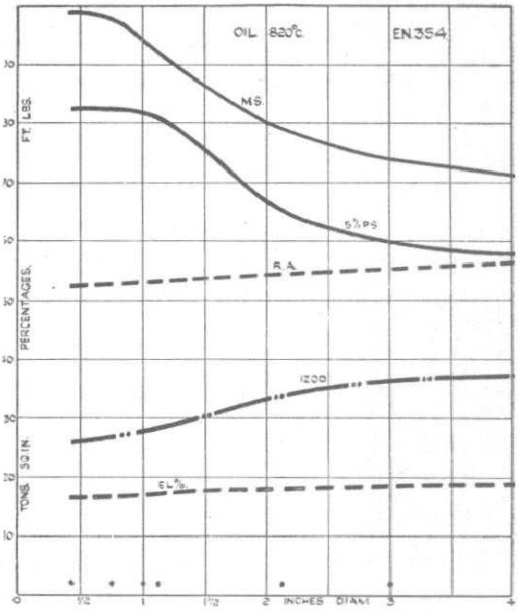

FIG. 27

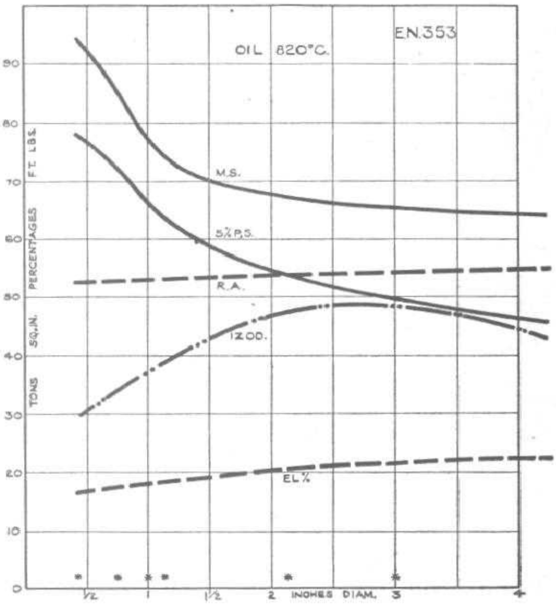

FIG. 26

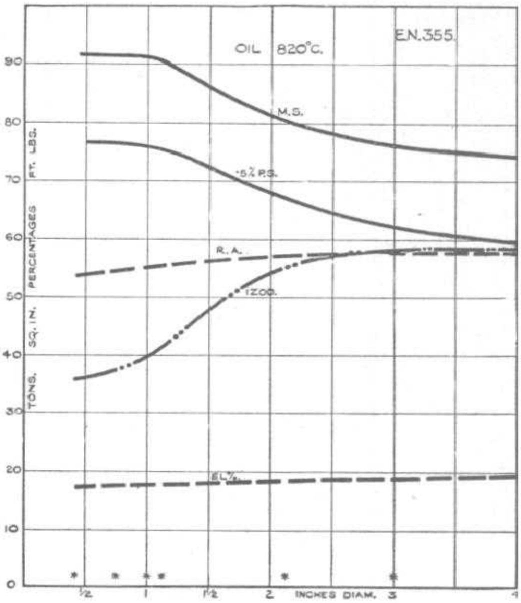

FIG. 28

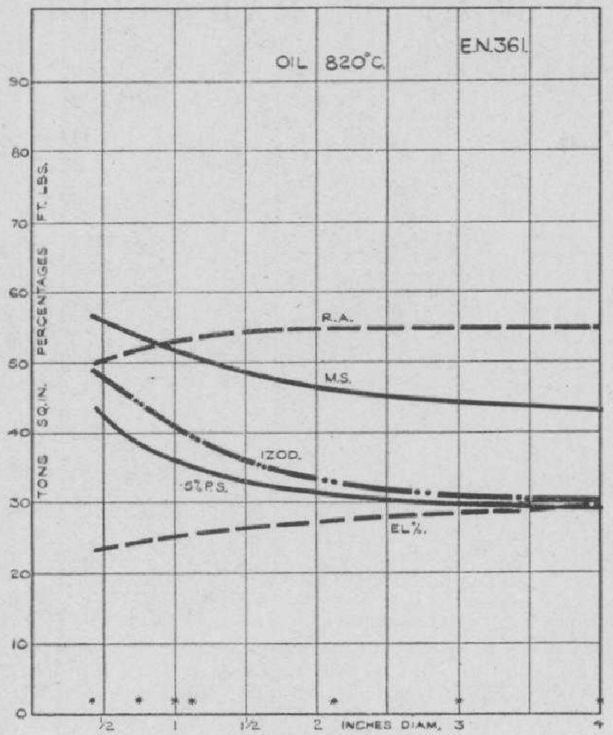

FIG. 29

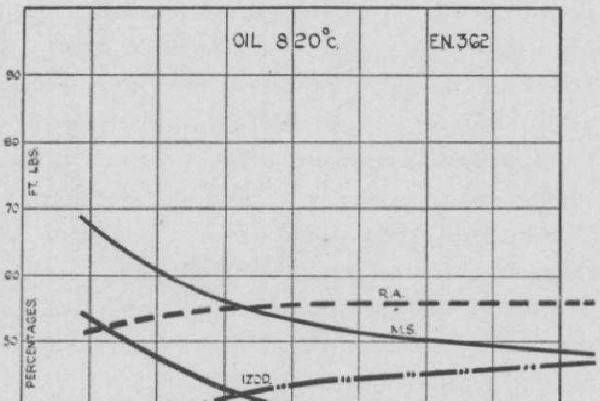

FIG. 30

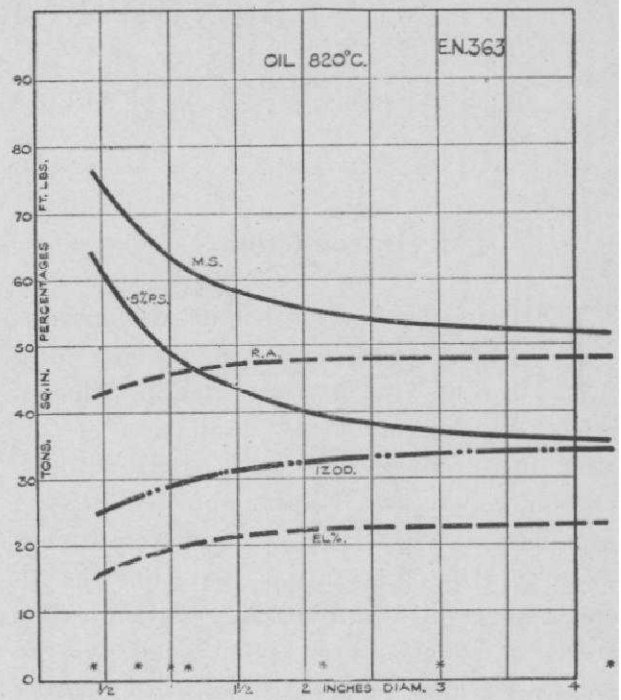

FIG. 31

(e) Eighty-five tons/sq. in. minimum tensile level, En 39, 355. Results for only the double-quench treatment are available for En 39. En 355 shows a rather greater degree of mass effect in tensile than En 39, but the ductility is almost exactly the same.

Generally speaking, the new steels compare quite well with the old ones, and there is no reason to believe that, by proper selection, just as good service should not be obtained from them.

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