CAST NICKEL ALLOY STEELS – ENGINEERING PROPERTIES

A PRACTICAL GUIDE TO THE USE OF NICKEL-CONTAINING ALLOYS

Nº 4393

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Cast nickel alloy steels

Engineering properties of four low-alloy commercial grades

Contents

The data and recommendations in this publication are based on practical experience and research and development work. They are as complete and accurate as possible at the time of publication. It is important to ensure that the information is applicable to the particular project and/or practice under consideration.

First published 1975

Cast nickel alloy steels for general engineering use

Few national specifications exist for high-tensile low-alloy steel castings which relate minimum mechanical property requirements to appropriate composition ranges. Table 1 summarizes national specifications (or an authoritative classification of cast steels where a national specification does not exist) which are relevant to low-alloy nickel steels. In the majority of cases tensile properties are specified and in some instances impact values are also quoted, but in many cases the type of steel to be used is either left to the discretion of the supplier or left for agreement between the supplier and purchaser. Usually, suppliers of castings are able to call on their experience and on 'in-house' data records to assist the purchaser in the best choice of composition for the proposed application, if adequate service details are given and the service requirements can be adequately defined in terms of basic engineering properties. Quite often the latter is a matter of approximate estimation; furthermore there is always the problem of equating dynamic loading conditions to conventional static tests used to check the quality of castings. Indeed some specifications for cast steel merely require a sample of the steel to give certain mechanical properties when cast and heat treated as a test coupon of 20–30 mm (¾–1¼ in.) section thickness. Sometimes the test coupon is cast-on to the casting and not separated from it until after heat treatment but, even so, unless the maximum effective section size of the casting is similar to that of the test coupon, the properties of the coupon do not give a reliable measure of those to be expected in all parts of the casting itself. Such test results are usually accepted as indicative of the quality of the steel cast from a particular melt. Nevertheless, when selecting a steel to meet particular specification requirements, consideration must also be given to the effect of section size and hardenability on the mechanical properties of the actual casting. This is especially important if the strength and toughness in all the sections of a casting of complex shape (with appreciable variations in section size) are to exceed the particular minima dictated by the service conditions.

The engineer/designer is often confronted by the task of locating and assessing the properties of different types of cast steel. However, compared with the information available for wrought steels, suitable data are not readily available. This publication provides mechanical property data for four well established cast nickel alloy steels within various ranges of tensile strength and includes information on the effects of section size wherever relevant data are available.

Manufacturers of nickel alloy steel castings often supply proprietary compositions to meet various mechanical property specifications. A survey of the types available in many different countries shows that the majority of these steels can be classified into the four composition ranges detailed in Table 2. The corresponding mechanical property data have been collated from various sources and form the basis of the typical properties given in this publication. Of the steels described, the greatest use is made of the 0·6 and 1·5 per cent Ni-Cr-Mo grades since they provide a good combination of properties over a useful range of section thicknesses and in castings of complex design.

Diagrams showing the effects of heat treatment and section size on mechanical properties have been derived from the available data and are presented on pages 14 to 19. The beneficial effects of increasing alloy content when higher tensile strengths are required, and when castings have large section thickness or appreciable variations in section size, can be seen by a comparison of the various diagrams. The diagrams showing the effects of section size on tensile properties clearly indicate that if the cast test coupon used for quality control is of a size appreciably smaller than the actual casting, the mechanical property test results can be misleading, particularly in the case of the lower alloy steels. Due consideration should therefore be given to this fact in selecting the type of steel to be used. Alternatively, precautions should be taken to check the properties of a test coupon of ruling section equivalent to that of the casting.

Heat treatment and section size effects

High-tensile steel castings are normally supplied in the normalized and tempered, oil- or water-quenched and tempered conditions, or in the annealed condition to facilitate machining operations. In the latter case they are subsequently re-heat treated by the purchaser. Normal heat treatment temperature ranges for the steels included in this publication are given in Table 2. Quench-hardening followed by tempering is often preferred for the 0·6 and 1·5 per cent Ni-Cr-Mo steels since for a given tensile level it usually provides the best combination of mechanical properties. This superiority of quench-hardening is generally shown by higher yield stress, toughness and ductility values, with reduction-of-area values being the more discriminating criterion of ductility.

The risk of 'quench cracking' in castings of complex shape which have sharp changes in section thickness can be minimized by reducing the rate of cooling in quenching and it is sometimes preferable to use a higher alloy steel which may be air-hardened rather than using one of lower alloy content which requires quench-hardening to achieve given mechanical properties. Satisfactory properties can often be achieved by normalizing without recourse to tempering although omission of the latter may introduce greater risks associated with residual internal stress. These stresses result from thermal gradients and transformation volume changes during cooling from the austenitizing temperature which, if at too high a level, may impair the ability of the casting to withstand applied stresses in service.

Quench-hardening is invariably employed to attain the highest tensile strengths in a given steel. However, designers should liaise closely with suppliers of castings when aiming to utilize the high tensile strengths attainable by quenching the higher alloy grades, i.e., 2·5 and 3·5 per cent Ni-Cr-Mo, since complex shapes may cause quench cracking problems. On the other hand, such steels can be used to overcome quench cracking if they are used in the air-hardened and tempered condition in preference to quench-hardened steels of lower alloy content.

Section size, apart from influencing the primary grain structure obtained on solidification of a casting, limits the cooling rate which can be achieved during quenching or air cooling in heat treatment and hence limits the mechanical properties attainable. It is usually necessary to compensate for an increase in section size by increasing the alloy content of the steel casting.

Fracture toughness – a design criterion

Fracture toughness is an important property since it defines the ability of a steel to resist initiation and rapid propagation of cracks from regions of stress concentration. Such

Country and specification or authoritative classification	Heat treatment condition	Tensile strength			Yield stress			Elongation Lo 5·65 √ So per cent		Impact value				Hardness HB	Composition Weight per cent						
		As specified Rm, σB	Converted		As specified Rs, σs	Converted				As specified	Converted				C	Si	Mn	Ni	Cr	Mo	Other
United Kingdom †																					
BS 3100:76 (Steel castings for general engineering purposes)					Proof stress, Rp 0·2					Charpy V-notch											
		N/mm²	tonf/in²	kgf/mm²	N/mm²	tonf/in²	kgf/mm²			J	ft lbf	kgf m/cm²									max.
Grade BT1	—	690–850	45–55	70–87	495	32	50			35	26	4·5		201–255‡	—	—	—	—	—	—	{S P} 0·05
Grade BT2	—	850–1000	55–65	87–102	585	38	60			25	18	3·2		248–302‡	—	—	—	—	—	—	{S P} 0·04
Grade BT3	—	1000–1160	65–75	102–118	695	45	71			20	15	2·5		293–341‡	—	—	—	—	—	—	{S P} 0·03
BS 3146: Part 1:74 (Investment castings)					Rp 0·2					Izod											
		N/mm²	kgf/mm²	tonf/in²	N/mm²	kgf/mm²	tonf/in²			ft lbf	J	kgf m/cm²									
Type CLA3	Hardened and tempered	700–850	71–87	45–55	495	50	32	11		25	34	4·3		201–255‡	—	—	—	—	—	—	{S P} 0·035
Type CLA4	"	850–1000	87–102	55–65	585	60	38	11		15	20	2·6		248–302‡	—	—	—	—	—	—	{S P} 0·035
Type CLA5 Grade A	"	1000	102	65	880	90	57	9		30	41	5·2		269–321‡	—	—	—	—	—	—	{S 0·020 P 0·025
Type CLA5 Grade B	"	1160	118	75	1000	102	65	5		30	41	5·2		341–388‡	—	—	—	—	—	—	{S 0·020 P 0·025
					Rp 0·2																
		M Pa (=N/mm²)	kgf/mm²	tonf/in²	M Pa (=N/mm²)	kgf/mm²	tonf/in²	Lo = 5·65 √ So	R.A. %												
BS HC9:74 (Aerospace (series)	OQ or WQ & T	880–1080	90–110	57–70	700	71	45	8	30	30	41	5·2		262–321	0·22–0·34	0·3–0·6	0·3–0·8	0·5–3·0	0·5–1·3	0·2–0·7	{S 0·025 P 0·025 Cu 0·4
BS HC10:74 (Aerospace (series)	OQ & T	1150–1300	117–133	74–84	940	96	61	5	14	10	14	1·7		331–401	0·22–0·34	0·3–0·6	0·3–0·8	0·5–3·0	0·5–1·3	0·2–0·7	{S 0·025 P 0·025 Cu 0·4

		Tensile strength				Rp 0·1				Lo = 5·65 √ So	R.A. %	Impact value			Hardness HB	C	Si	Mn	Ni	Cr	Mo	Other
		tonf/in²	kgf/mm²	N/mm²	kgf/mm²	tonf/in²	kgf/mm²	N/mm²	kgf/mm²													
DTD 5172		55–65	—	850–1000	87–102	43	—	660	68	12	30	30	41	5·2	248–302	—	—	—	—	—	—	—
DTD 666		60	94·5	930	—	45	71	690	—	12	30	30	41	5·2	269	—	—	—	—	—	—	{S 0·02 P 0·05
DTD 705		75–82	118–129	1160–1270	—	60	94·5	930	—	7	14	10	14	1·7	340	—	—	—	—	—	—	{S 0·02 P 0·05
DTD 5072		75–85	118–134	1160–1310	—	60	94·5	930	—	7	14	10	14	1·7	340–390	—	—	—	—	—	—	{S 0·02 P 0·05

Country and specification or authoritative classification	Heat treatment condition	Tensile strength			Yield stress			Elongation		Impact value				Hardness HB	C	Si	Mn	Ni	Cr	Mo	Other
France					Rs					Charpy U-notch											
CTIF(1) Constructional grades:		N/mm²	kgf/mm²	tonf/in²	N/mm²	kgf/mm²	tonf/in²			daJ/cm²	J	kgf m/cm²	ft lbf		Nominal composition						max.
30NCD2-M	N & T	650	66	42	400	41	26	13		6	30	6·1	22	—	0·3	0·3	0·5	0·6	0·6	0·2	{S 0·04 P 0·04
	OQ & T up to 600–625°C	850(2)	87	55	700(2)	71	45	11(2)		6(2)	30	6·1	22	—							
30NCD8-M	N & T	750	76	49	500	51	32	14		6	30	6·1	22	—	0·3	0·3	0·6	2·0	1·0	0·3	{S 0·04 P 0·04
	OQ & T up to 600°C	900(2)	92	58	650(2)	66	42	12(2)		6(2)	30	6·1	22	—							
32NCD 08 08-M	N & T	750	76	49	600	61	39	14		5	25	5·1	18	—	0·32	0·3	0·5	2·0	2·0	0·6	{S 0·04 P 0·04
	OQ & T up to 650°C	950(2)	97	62	800(2)	82	52	13(2)		5(2)	25	5·1	18	—							
30NCD14-M	N & T up to 600°C	900	92	58	700	71	45	8		4	20	4·1	15	—	0·3	0·4	0·7	3·5	1·0	0·25	{S 0·04 P 0·04
	N & T up to 650°C	800	82	52	600	61	39	10		7	35	7·1	26	—							
35NCM6-M	N & T	900	92	58	600	61	39	9		4	20	4·1	15	—	0·35	0·4	1·4	1·5	1·4	0·3	{S 0·04 P 0·04
CTIF(1) Wear-resisting grades:																					
30NCD2-M	N & T	650	66	42	—	—	—	15		6	30	6·1	22	190 (360(3)(4))	0·3	0·6	0·8	0·6	0·6	0·2	{S 0·04 P 0·04
30NCD4-M	N & T	750	76	49	—	—	—	14		5	25	5·1	18	(400(3)(4))	0·3	0·5	0·8	1·0	0·6	0·3	{S 0·04 P 0·04
20NCD6-M	N & T	700	71	45	500	51	32	12		3	15	3·1	11	(350(5))	0·2	0·35	0·8	1·4	0·9	0·2	{S 0·04 P 0·04
30NCD8-M	N & T	750	76	49	—	—	—	14		6	30	6·1	22	(450(3))	0·3	0·3	0·6	2·0	1·0	0·3	{S 0·04 P 0·04
32NCD08 08-M	N & T	750	76	49	600	61	39	14		5	25	5·1	18	(480(3))	0·32	0·3	0·5	2·0	2·0	0·6	{S 0·04 P 0·04
30NCD14-M	N & T up to 600°C	900	92	58	700	71	45	8		4	20	4·1	15	(450(3))	0·3	0·4	0·7	3·5	1·0	0·25	{S 0·04 P 0·04
	N & T up to 650°C	800	82	52	600	61	39	10		7	35	7·1	26	(450(3))							
35NCD1605-M	N & T	900	92	58	—	—	—	8		4	20	4·1	15	(500(3))	0·35	0·5	0·8	4·0	1·2	0·4	{S 0·04 P 0·04 Cu 0·5
Germany																					
SEW(6) 510–62. GS-40 NiCrMo 656 (Werkstoff Nr. 1·6748)					Rs					DVM test-piece											
		kgf/mm²	N/mm²	tonf/in²	kgf/mm²	N/mm²	tonf/in²			kgf m/cm²	J	ft lbf									
Grade 1 <30 mm	—	75–90	740–880	48–57	55	540	35	13		5	34	25		—							
30–100 mm	—	75–90	740–880	48–57	55	540	35	12		4	27	20		—							
Grade 2 <30 mm	—	90–105	880–1030	57–67	70	690	44	11		4	27	20		—	0·37–0·44	0·3–0·5	0·5–0·8	1·3–1·7	1·1–1·5	0·5–0·7	—
30–100 mm	—	90–105	880–1030	57–67	70	690	44	10		3	21	15		—							
Grade 3 <30 mm	—	105–120	1030–1180	67–76	85	830	54	8		3	21	15		—							
30–100 mm	—	105–120	1030–1180	67–76	85	830	54	7		2(7)	14	10		—							

Readers are recommended to consult the latest issues of national specifications for up-to-date and comprehensive information pertaining to the use of those specifications. Extracts from British Standards (BS) are reproduced by permission of the British Standards Institution, 2 Park Street, London W1A 2BS.

† Certain steels outside the scope of this publication are excluded. These comprise: nickel alloy steel castings for case-hardening. 3½ per cent nickel steel castings for use at low temperatures.

‡ If specified by purchaser.

(1) To be published.
(2) Average value.
(3) Hardness values in parenthesis are those obtainable on the surface by suitable heat-treatment.
(4) Higher surface hardness may be obtained by localised hardening heat treatment.
(5) Surface hardness attainable by localised hardening heat treatment.
(6) Stahl-Eisen-Werkstoffblatt.
(7) Not guaranteed.

(continued)

Country and specification or authoritative classification	Heat treatment condition	Tensile strength As specified Rm, σB	Tensile strength Converted		Yield stress As specified Rs, σs	Yield stress Converted		Elongation Lo=5·65√So per cent		Impact value As specified	Impact value Converted			Hardness HB	Composition Weight per cent C	Si	Mn	Ni	Cr	Mo	Other
Austria					Rs																
Önorm M3181:1959		kgf/mm²	N/mm²	tonf/in²	kgf/mm²	N/mm²	tonf/in²														
Stg 60[8]	—	60	590	38	—	—	—	8		—	—	—	—	—	—	—	—	—	—	—	—
Stg 60S30[8]	—	60	590	38	30	290	19	15		—	—	—	—	—	—	—	—	—	—	—	—
Stg 60S36[8]	—	60	590	38	36	350	23	15		—	—	—	—	—	—	—	—	—	—	—	—
Italy					Rs					Mesnager (2mm deep U-notch)											
UNI 4010: 1958[9]		kgf/mm²	N/mm²	tonf/in²	kgf/mm²	N/mm²	tonf/in²			kgf m/cm²	J	ft lbf									max.
Type 3[9]	—	60	590	38	35	340	22	15		6	47	35		—	—	—	—	—	—	—	S 0·035 P 0·035
Type 4	—	70	690	44	45	440	29	12		5	39	29		—	—	—	—	—	—	—	S 0·035 P 0·035
Type 5	—	80	780	51	60	590	38	10		4	31	23		—	—	—	—	—	—	—	S 0·035 P 0·035
India					Rp 0·5					Izod[10]											
IS 2664:73		kgf/mm²	N/mm²	tonf/in²	kgf/mm²	N/mm²	tonf/in²	Lo=5·65√So	R.A. %	kgf m	J	ft lbf	kgf m/cm²								
Grade 1 CS65	—	65	640	41	40	390	25	17	37	3·5	34	25	4·4	190	—	—	—	—	—	—	—
Grade 2 CS71	—	71	700	45	57	560	36	15	35	3·5	34	25	4·4	207	—	—	—	—	—	—	—
Grade 3 CS85	—	85	830	54	71	700	45	12	30	2·8	27	20	3·5	248	—	—	—	—	—	—	—
Grade 4 CS105	—	105	1030	67	87	850	55	8	22	2·0	20	14	2·5	311	—	—	—	—	—	—	—
Grade 5 CS125	—	125	1230	79	102	1000	65	5	12	—	—	—	—	363	—	—	—	—	—	—	—
U.S.A.[14]					Rs					Charpy V-notch											
ASTM A148–71:		10³lbf/in²	N/mm² (kgf/mm²)	tonf/in²	10³lbf/in²	N/mm² (kgf/mm²)	tonf/in²	Lo=4·5√So	R.A. %	ft lbf	J	kgf m/cm²									max.
Grade 90–60	Annealed	90	620 (63)	40	60	410 (42)	27	20	40	—	—	—		—	—	—	—	—	—	—	S 0·06 P 0·05
Grade 105–85	Annealed	105	720 (74)	47	85	590 (60)	38	17	35	—	—	—		—	—	—	—	—	—	—	S 0·06 P 0·05
Grade 120–95	Normalized	120	830 (84)	54	95	660 (67)	42	14	30	—	—	—		—	—	—	—	—	—	—	S 0·06 P 0·05
Grade 150–125	N & T or Q & T	150	1030 (105)	67	125	860 (88)	56	9	22	—	—	—		—	—	—	—	—	—	—	S 0·06 P 0·05
Grade 175–145	N & T or Q & T	175	1210 (123)	78	145	1000 (55)	65	6	12	—	—	—		—	—	—	—	—	—	—	S 0·06 P 0·05
ASTM A486–71:															max.						max.
Class 90	N, N & T or Q & T	90	620 (63)	40	60	410 (42)	27	20	40	25[11] at 70 F 15[11] at 0 F 15[11] at −50 F	34 20 20	4·3 2·6 2·6		—	0·35	other elements may be added					S 0·06 P 0·05
Class 120	Q & T	120	830 (84)	54	95	660 (67)	42	14	30	30[11] at 70 F 25[11] at 0 F 15[11] at −50 F	41 34 20	5·2 4·3 2·6		—	0·35	other elements may be added					S 0·06 P 0·05
ASTM A487–71a:															max.	max.					max.
Class 4N	N & T	90	620 (63)	40	60	410 (42)	27	20	40	15[12]	20	2·6		—	0·3	0·8	1·0 max.	0·4–0·8	0·4–0·8	0·15–0·3	S 0·045 P 0·04 Cu 0·50 W 0·10
Class 4Q	Q & T	105	720 (74)	47	85	590 (60)	38	17	35	15[12]	20	2·6		—							
Class 4QA	Q & T	115	790 (81)	51	95	660 (67)	42	15	35	15[12]	20	2·6		—							
Class 5N	N & T	105	720 (74)	47	70	480 (49)	31	18	35	15[12]	20	2·6		—	0·3	0·8	1·0–1·4	0·4–0·8	0·4–0·8	0·15–0·25	S 0·045 P 0·04 Cu 0·50 W 0·10
Class 5Q	Q & T	105	720 (74)	47	85	590 (60)	38	15	30	15[12]	20	2·6		—							
Class 6N	N & T	115	790 (81)	51	80	550 (56)	36	18	30	15[12]	20	2·6		—	0·38	0·8	1·3–1·7	0·4–0·8	0·4–0·8	0·3–0·4	S 0·045 P 0·04 Cu 0·50 W 0·10
Class 6Q	Q & T	120	830 (84)	54	95	660 (67)	42	12	25	15[12]	20	2·6		—							
Class 10N	N & T	100	690 (70)	45	70	480 (49)	31	18	35	15[12]	20	2·6		—	0·3	0·8	0·6–1·0	1·4–2·0	0·55–0·9	0·2–0·4	S 0·045 P 0·04 Cu 0·50 W 0·10
Class 10Q	Q & T	125	860 (88)	56	100	690 (70)	45	15	35	15[12]	20	2·6		—							
ASTM A643–71:																					
Grade B Class 1	N & T or Q & T	80–110	550–760 (56–77)	36–49	50	340 (35)	22	22	35	—	—	—	—	—	0·25	0·6	1·15–1·50	0·45–1·0	0·4 max.	0·45–0·6	S 0·035 P 0·035 V 0·03 Cu 0·50 W 0·10
Grade D Class 1	N & T or Q & T	105–135	720–930 (74–95)	47–60	85	590 (60)	38	15	30	—	—	—		—	0·20	0·6	0·4–0·7	2·75–3·90	1·5–2·0	0·4–0·6	S 0·02 P 0·02 V 0·03 Cu 0·50 W 0·10
Class 2	N & T or Q & T	115–145	790–1000 (81–102)	61–65	100	690 (70)	45	13	30	—	—	—		—							
SAE J435b:																					
Grade 090	—	90	620 (63)	40	60	410 (42)	27	20	40	—	—	—		187–241*	—	—	—	—	—	—	S 0·06 P 0·05
Grade 0105	—	105	720 (74)	47	85	590 (60)	38	17	35	—	—	—		217–248*	—	—	—	—	—	—	S 0·06 P 0·05
Grade 0120	—	120	830 (84)	54	95	660 (67)	42	14	30	—	—	—		248–311*	—	—	—	—	—	—	S 0·06 P 0·05
Grade 0150	—	150	1030 (105)	67	125	860 (88)	56	9	22	—	—	—		311–363*	—	—	—	—	—	—	S 0·06 P 0·05
Grade 0175	—	175	1210 (123)	78	145	1000 (102)	65	6	12	—	—	—		363–415*	—	—	—	—	—	—	S 0·06 P 0·05
SAE/AMS[13] AMS 5329B:73					Rp 0·2			Lo=2 in. (51 mm) or 4·5√So						HRC							
	Annealed	—	—	—	—	—	—	—		—	—	—		≤30	0·28–0·36	0·5–0·9	0·6–1·0	1·65–2·0	0·65–1·0	0·3–0·45	Cu 0·35 S 0·025 P 0·025
	O.Q. and double tempered	180	1240 (127)	80	160	1100 (112)	71	5		—	—	—		40–45							

(8) For these specifications of relatively low strength virtually unalloyed steel may be suitable for medium-size castings. For castings of thick section a nickel alloy steel may be used to ensure adequate hardenability and attainment of the properties required.
(9) Standard undergoing revision.
(10) Where due to mass design it is not possible to liquid quench the castings, it may not be possible to achieve the specified
(11) For sections up to 2 in (51 mm) thickness.
(12) This minimum impact value may be included by contract agreement.
** For sections up to 3in (76 mm) thickness.*
(13) Aerospace material specification.
(14) Certain steels outside the scope of this publication are excluded. These comprise castings for high- and low-temperature service.

Table 2. *Four internationally-available nickel alloy steels. Compositions and heat-treatment temperatures.*

Steel	Composition Weight per cent					Usual temperature range, °C		
	C	Mn	Ni	Cr	Mo	Normalizing	Oil- or water-quenching	Tempering
0·6% Ni-Cr-Mo	0·26–0·36	0·6–1·0	0·4–0·8	0·4–0·8	0·15–0·35	870–930	840–890	200–690
1·5% Ni-Cr-Mo	0·30–0·40	0·4–0·8	1·3–1·9	0·6–1·0	0·20–0·40	860–920	830–880	200–690
2·5% Ni-Cr-Mo	0·30–0·40	0·4–0·8	2·0–2·8	0·6–1·0	0·30–0·60	850–910	820–870	200–670
3·5% Ni-Cr-Mo	0·30–0·40	0·4–0·8	3·2–4·0	1·0–1·4	0·30–0·60	850–910	810–860	200–650

Note: The mechanical properties quoted in this publication refer to steels which generally conform to the above composition ranges. However, steels with lower or higher carbon contents than those shown may be used for special purposes, e.g., to give higher hardness for increase of wear resistance. Selective surface hardening (flame) is also employed for that purpose, while some components (usually of lower carbon content) may be carburized on wear resisting surfaces.

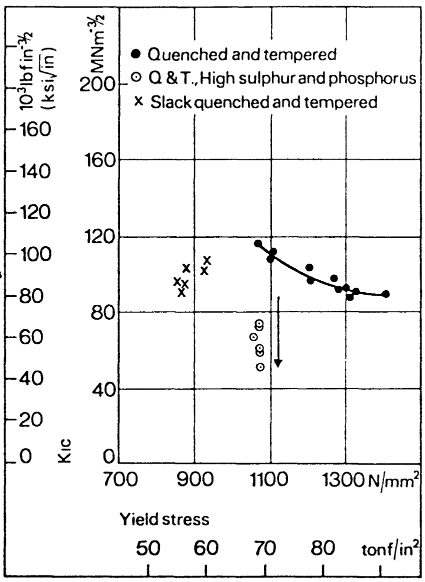


Figure 1. *Room-temperature fracture toughness (Kic) of cast 1·5 per cent Ni-Cr-Mo steel (after John F. Wallace: 'casteel', Spring 1974, vol. 8, No. 2. Steel Founders Soc. of America).*

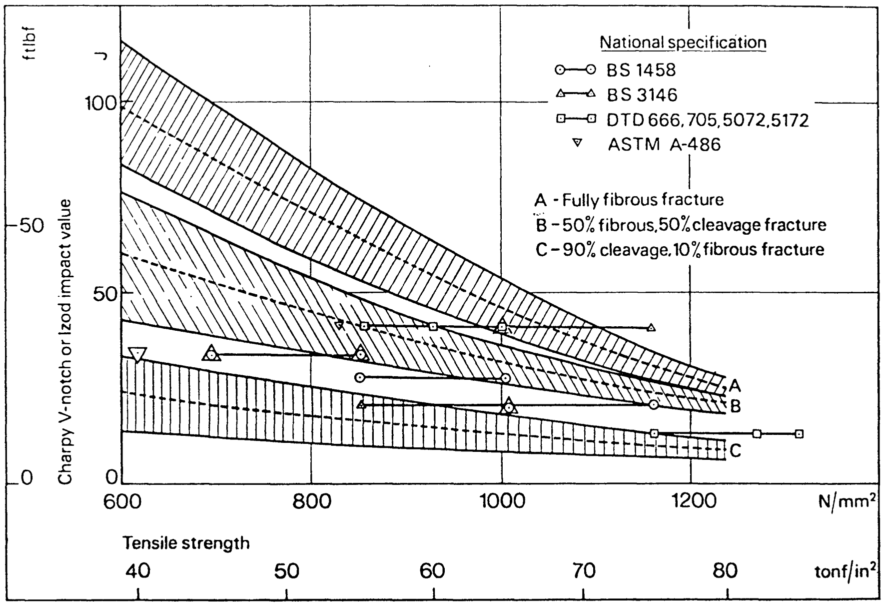


Figure 2. *Impact test fracture appearances normally expected in low-alloy steel castings having given tensile strengths and impact values. The tensile strength and impact value requirements of some national specifications which stipulate an impact test are shown for comparison.*

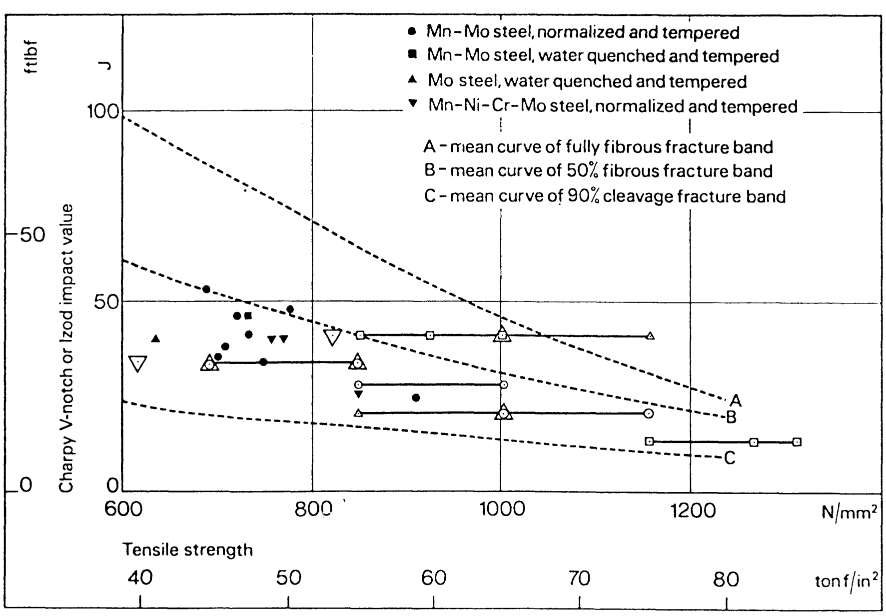


Figure 3. *Representative tensile strength/impact value test data for several low-alloy steel castings which meet the mechanical property requirements of some national specifications (see Figure 2 for legends). The impact fractures of these steels would probably show 50 per cent, or more, cleavage (brittle) fracture.*

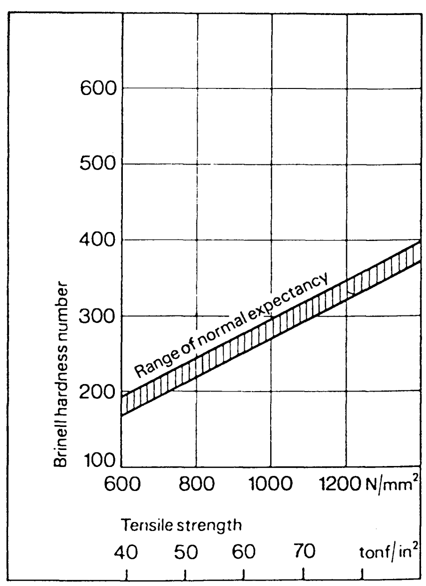


Figure 4. *Brinell hardness as a function of tensile strength for low-alloy cast steels, regardless of heat treatment.*

regions may be caused by the presence of internal or superficial defects in an applied stress field. These defects are often unavoidable and may comprise inclusions, microcracks, notches formed during machining and those inherent in the design/manufacturing process, or cracks developed in service as a result of fatigue, stress corrosion and other environmental factors. Stress concentrations are sometimes relieved by local yielding but yielding can be prevented by the constraint imposed by surrounding metal, particularly in large sections, and in materials of high yield strength. The larger the defect the greater is the stress intensity in its vicinity and the lower the operational stresses which can be borne. Alternatively, as the applied stress increases, the defect size which can be tolerated decreases rapidly. A steel having high fracture toughness will withstand operational stresses near to the maximum permissible stress, even in the presence of relatively large defects, whereas steel of low fracture toughness is likely to fail at lower applied stresses if even minor defects are present. In recent years sophisticated methods of assessing fracture toughness have been developed and applied to wrought steels, but the application of these procedures to cast steels has so far yielded only limited data. Nevertheless, research studies based on the principles of linear elastic fracture mechanics are currently in progress to obtain fracture toughness data for cast steels similar to those available for many wrought steels, in terms of the plane strain fracture toughness parameter K_{1c}. This involves testing with a known applied stress in the presence of a crack of established dimensions, the test being designed with sufficient constraint on the sample to ensure that 'plane strain' conditions prevail. Given the K_{1c} value of a steel the critical size of crack, or flaw, which may cause brittle fracture in service may be obtained from the relationship:

$$K_{1c}=Q\sigma\sqrt{\pi a}$$

where the value of Q depends on the geometry and position of the crack, σ is the gross applied stress normal to the crack, and 'a' is the critical depth of a surface crack or half the critical width of an embedded crack. In the general case, Q can be shown not to exceed 1·2.

Plane strain fracture toughness data for a 1½ per cent nickel-chromium-molybdenum cast steel are shown in Figure 1. The beneficial effect of proper quenching to ensure satisfactory hardening is demonstrated by the relatively lower fracture toughness of the slack-quenched steel, while increase of sulphur and phosphorus levels in the range S+P=0·03 to 0·12 per cent also reduced fracture toughness.

Notch impact strength – the 50% fibrous fracture criterion

In the absence of adequate K_{1c} data for cast steels in general, recourse must be made to the available data from impact tests. Table 1 shows that some specifications stipulate minimum impact values, but it is now generally recognised that while such data are useful for quality control they cannot be applied directly in design. For most casting design purposes, the appearance of the fracture in an impact test (i.e., the proportions of fibrous and brittle areas) is superior to the energy absorption value as a criterion of fracture toughness. Therefore, it is of practical importance to establish correlations between impact energy value and probable fracture appearance.

In the early studies of brittle fracture in wrought steels correlations were established between impact value and probability of brittle fracture in service for certain classes of steel where service data were available on satisfactory and failed structures. In effect, these correlations involved a major dependence on impact fracture appearance. Subsequently it became generally accepted that for most wrought and cast steels, unless stresses near to the permissible upper limit and/or large defects are involved, uninhibited cracking is unlikely to occur in service if in an impact test at the lowest operating temperature the fracture appearance shows over 50 per cent fibrous fracture. This, however, is only true if the impact transition curve does not show a sharp fall in energy absorption values and per cent fibrous fracture over a narrow temperature range. An alternative way of expressing this is to say that the 50 per cent fibrous fracture appearance transition temperature (FATT) should be well below the normal service temperature. Thus a small shift in the transition curve towards higher temperatures (which may well occur in an actual casting, as distinct from test pieces taken from cast test coupons) will not cause a decrease in the per cent fibrous fracture to an unsatisfactorily low value under service conditions. In the case of castings which are to operate under extremely cold conditions, e.g. arctic regions, it is advisable to determine the impact transition curve over a range of test temperatures which span the service temperature. Typical impact transition curves are included in the data shown for three of the steels reviewed in this publication.

Figure 2 shows the effect on the impact fracture appearance of various combinations of tensile strength and Charpy V-notch impact values. It can be seen that for a given fracture appearance, the lower the strength the higher must be the impact value. The diagram also includes the impact values and tensile strengths stipulated in several of the specifications given in Table 1. It shows that, in some instances, castings may be obtained which satisfy these specifications but have a lower 'fracture toughness' in terms of fracture appearance than is generally desirable. In defence of the specifications it must be emphasized that these quote minimum impact energy values and actual test values are usually in excess of the minimum. Nevertheless when high tensile castings of unproven compositions are contemplated for a given design and reliance is being placed entirely on specification impact toughness requirements, the purchaser might do well to remember the adage "Let the buyer beware". To amplify this point, Figure 3 shows the Mean Fracture Appearance curves of Figure 2 together with plot points for Tensile strength/Impact data obtained from cast test coupons of several types of low-alloy steel. Each of these test castings satisfies the requirements of at least one of the specifications also shown on the diagram, but it appears probable that the impact fracture appearance of the steels illustrated would fail to meet, or only just meet, the 50 per cent fibrous criterion.

To assist the selection of a steel to meet specific impact fracture appearance requirements, in addition to particular mechanical property values, Figure 2 may be used in conjunction with the diagrams showing the effect of tensile strength on impact energy values of the various steels included in this publication.

Brinell hardness

The linear relationship between Brinell hardness and tensile strength of steel castings is well known but for convenience is reproduced in Figure 4. Brinell hardness is quoted in a few national specifications, see Table 1, but it is also widely used to check the uniformity of a batch of castings for which approval tensile tests have been made on representative samples or test coupons. It can also be useful in check tests made on castings after service where an indication is required of the nominal strength in the absence of recorded data.

Fatigue properties

The smooth-bar fatigue endurance limits of cast low-alloy nickel steels are, in the main, dependent on the tensile strengths to which the steels are heat treated. For given tensile strengths they are usually slightly higher than those of cast plain carbon steels and slightly less than those of wrought low alloy steels of comparable compositions tested in the direction of working. The endurance ratio of the cast steels (i.e. ratio of endurance limit to tensile strength) varies between approximately 0·4 and 0·5 for smooth-polished or lathe-turned test bars (see, for example, Table 3) and is independent of composition and heat treatment. The presence of a notch reduces the endurance ratios of both cast and wrought steels and the effect is greater the higher the tensile strength, see Figure 5. However, the effect of notches on the fatigue strength of cast steels is less than that for wrought steels because cast steels are less notch sensitive and, for this geometric condition, both

Table 3. *Typical fatigue strength data for cast 0·6 per cent and 1·5 per cent Ni-Cr-Mo steels.*

Steel	Heat treatment °C	Tensile strength		Endurance limit(1)				Endurance ratio		Fatigue strength reduction factor Ka	Notch sensitivity q
				Unnotched		Notched(2)					
		N/mm²	tonf/in² (kgf/mm²)	N/mm²	tonf/in² (kgf/mm²)	N/mm²	tonf/in² (kgf/mm²)	Unnotched	Notched		
0·6 Ni-Cr-Mo	Normalize 900 Temper 650	790	51 (81)	390	25 (40)	230	15 (23)	0·49	0·29	1·69	0·58
	Water quench 845 Temper 650	950	62 (97)	450	29 (46)	270	17 (28)	0·47	0·28	1·68	0·57
1·5 Ni-Cr-Mo	Normalize 900 Temper 605	870	56 (89)	440	28 (45)	240	16 (24)	0·50	0·28	1·79	0·66
	Water quench 830 Temper 550	1160	75 (118)	540	35 (55)	330	21 (34)	0·47	0·28	1·68	0·57

(1) $N=10^7$ cycles.
(2) $Kt=2{\cdot}2$.

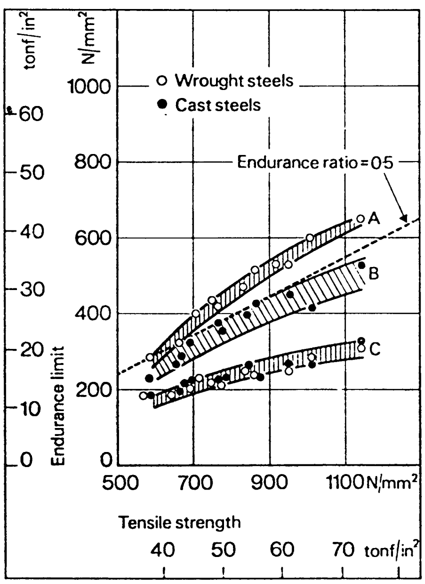


Figure 5. *Variation of fatigue endurance limit with tensile strength for comparable cast and wrought steels. (after Evans, Ebert and Briggs: Trans. ASTM, 1956, vol. 56).*
A – Wrought, unnotched
B – Cast, unnotched
C – Cast and wrought, notched. Theoretical stress concentration factor Kt=2·2

Table 4. *Nickel alloy cast steels. Physical properties.*

Property	
Density gm/cm³	7·97
lb/in³	0·288
Specific gravity	7·97
Specific heat J/kgK	420–460
cal/gm °C	0·10–0·11
Thermal conductivity W/m K	46·7
cal/cm s °C	0·112
Linear coefficient of thermal expansion 20–600°C 10^{-6}/K	14·5–16·25
Electrical resistivity μΩcm	15–20
Modulus of elasticity KN/mm²	200–210
10^6lbf/in²	20–30

materials have similar fatigue properties irrespective of whether the corresponding wrought steels are tested in the longitudinal or transverse directions of working. Similar equivalence of fatigue properties is obtained with lathe-turned surface finishes, which have negligible effect on cast material, whereas the fatigue properties of wrought steels are impaired by the slight notch effect of a lathe-turned finish.

Figure 5 shows the expected range of notched-bar endurance limits of cast steels at various tensile strengths for a theoretical stress concentration factor Kt=2·2. It will be seen that the notched fatigue strengths of both cast and wrought steels at any given tensile level are closely similar, consequently the effect of varying notch severity on the endurance limit of cast steels may be predicted to a near approximation from the curves shown in Figure 6 determined on wrought steel, used in conjunction with the upper band of Figure 5. For example, with a value of Kt=2·2 and a hardness level of 220 HB (i.e. tensile strength of about 760 N/mm² (49 tonf/in²)) a fatigue strength reduction factor Ka=1·82 is obtained from Figure 6. From Figure 5 the unnotched endurance limit for wrought steel at a tensile strength of 760 N/mm² is 420 N/mm² (27 tonf/in²), therefore the notched endurance limit is readily calculated from the

$$\text{equation Ka} = \frac{\text{unnotched endurance limit}}{\text{notched endurance limit}}$$

The value obtained is 230 N/mm² (15 tons/in²) which is virtually the same as that obtained from the lower band of Figure 5 for both wrought and cast steels at a tensile strength of 760 N/mm² and Kt=2·2. It is evident, therefore, that the relationships of Figures 5 and 6 are compatible and may be used conjointly to derive the approximate notched-bar endurance limits of cast steels for other values of Kt.

Since steel castings are mainly used with an as-cast surface finish on at least some part of the component, it is important to remember that some tests have shown that the as-cast surface can lower the endurance limit by approximately 30 per cent as compared with a polished surface. For wrought steel, a comparable finish, say, hot-rolled or as-forged, has been found to decrease the endurance limit by about 40 per cent at a tensile strength of 760 N/mm² (49 tonf/in²). There is thus little difference between the fatigue limits of comparable cast and wrought steels having similar tensile strengths if no special surface preparation is made.

The performance of a cast steel under fatigue conditions is likely to be reduced with increase in section size of the casting. The loss in properties is attributed to the so-called 'section size effect' which has two components: the first is the 'geometric component' dependent on increases in strain gradients and constraints imposed by the general mass of metal, i.e., increase of dimensions gives rise to increased stress concentrations; the second is associated with metallurgical factors such as the effect of mass on microstructure, soundness, distribution and size of inclusions and compositional segregation. In tests on standard size test pieces taken from several positions in castings of various sizes (thus eliminating the geometric component) it has been shown that the endurance limit decreases from surface to centre of the casting, see Figure 7. Although this variation is similar to that for the distribution of tensile strength across the sections, the similarity is not an exact parallel, because the endurance ratio tends to decrease slightly in passing from the surface to the centre of a section, see Figure 8. The endurance ratios from Figure 8 are replotted in Figure 9 to show the range of values to be expected within a casting as a function of section size. The indications are that, for a given steel, the lowest and highest values for a given section size encompass a

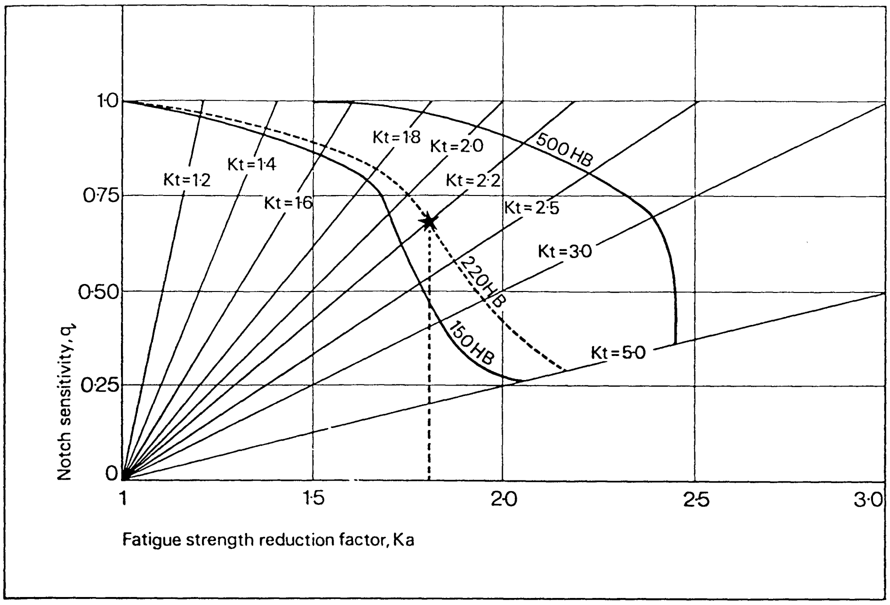


Figure 6. *Relationship between notch sensitivity (q), fatigue strength reduction factor (Ka) and theoretical stress concentration factor (Kt) for wrought steel at various hardness levels (after Johnson and Lipson: Product Engineering, Oct. 1947, vol. 18. The relationships shown for Kt=2·2 and 220HB are interpolations of the original data).*

$$q = \frac{Ka-1}{Kt-1}, \quad Ka = \frac{\text{unnotched endurance limit}}{\text{notched endurance limit}}$$

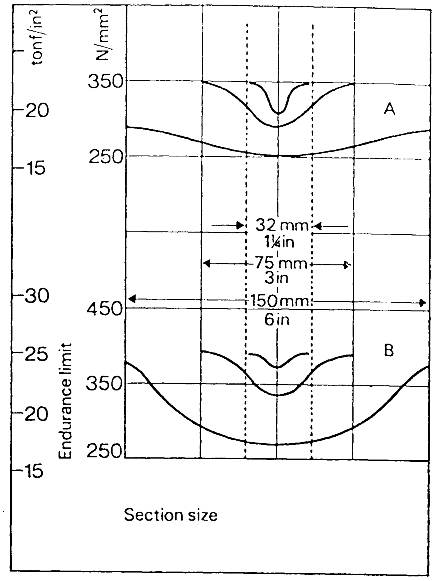


Figure 7. *Distribution of fatigue endurance limit of cast 0·6 per cent Ni-Cr-Mo steel within various section sizes. (after Evans, Ebert and Briggs: Proceedings ASTM, 1956, vol. 56).*

A – Normalized and tempered
B – Quenched and tempered

range of about 10 per cent difference in endurance ratio. This slight reduction in endurance ratio at the centres of large sections would probably be of negligible influence on the performance of the whole section in bending fatigue since the outer fibres generally receive the maximum stress in service and it is the properties at and near the surface of the section which would largely dictate the overall performance. The effect of the geometric component of size must also be taken into account, but this is difficult to predict quantitatively since the available information is meagre and inconclusive; however it is to be expected that the endurance ratio will be impaired in large sections because of the geometric effect.

Summary of mechanical properties and applications

Typical tensile and impact properties of the four cast nickel alloy steels included in this publication are summarized in Table 5, together with a brief outline of applications. It will be noted that steels of these types are considered most suitable for service conditions demanding high resistance to shock and severe dynamic stressing where optimum 'fracture toughness' and fatigue strength are all-important.

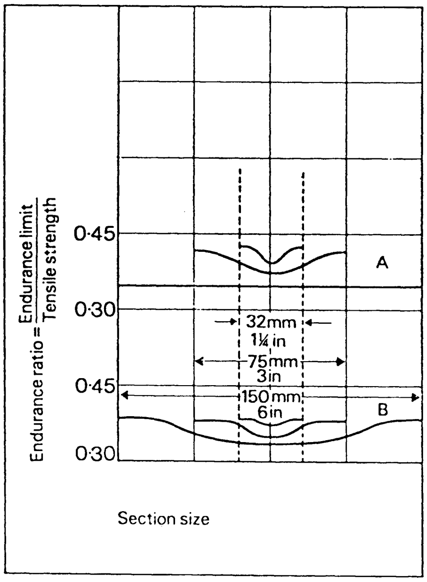


Figure 8. *Distribution of fatigue endurance ratio within various section sizes of cast 0·6 per cent Ni-Cr-Mo steel. (after Evans, Ebert and Briggs: Proceedings ASTM, 1956, vol. 56).*

A – Normalized and tempered
B – Quenched and tempered

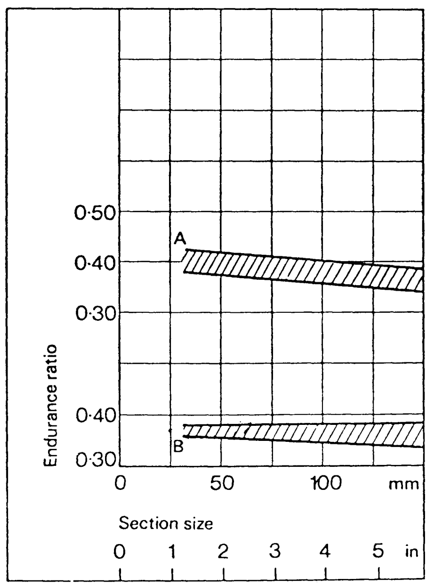


Figure 9. *Ranges of fatigue endurance ratios obtained with small specimens taken from several positions within 0·6 per cent Ni-Cr-Mo steel castings of various section sizes. (after Evans, Ebert and Briggs: Proceedings ASTM, 1956, vol. 56).*

A – Normalized and tempered
B – Quenched and tempered

Table 5. *Summary of typical mechanical properties of cast nickel alloy steels and scope of applications.*

Steel type	Heat treatment condition	Section thickness		Tensile strength		0·2% proof stress(1)		Elongation(1) Lo = 5·65 √So	Reduction of area(1)	Charpy V-notch impact value(1)		50% fibrous FATT(1)(2)	Per cent fibrous fracture in impact test at 20 °C	Hardness HB	Applications
		inch	mm	N/mm² *	tonf/in² (kgf/mm²)	N/mm² *	tonf/in² (kgf/mm²)	per cent	per cent	J *	ft lbf (kgf m/cm²)	°C	(estimated from Fig. 1)		
0·6% Ni-Cr-Mo	N & T	1–4	25–102	700	45 (71)	420–530	27–34 (43–54)	15–22	40–50	45–60	33–44 (5·7–7·6)	—	45–55	205	General engineering castings. Earth moving equipment: buckets, fabricated bucket corner sh and hitch plates. Tractor drawn scraper goosenecks. Sprockets, caterpillar track shoes, gears and pinions. Power shovel deck frames. Dredge impeller pump castir Excavator slewing rings. Crane wheels. Oil well valve bodies.
				800	52 (82)	560–670	36–43 (57–68)	11–17	30–40	15–25	11–18 (1·9–3·2)	—	10–20	230	
		4–6	102–152	700	45 (71)	390–420	25–27 (40–43)	12–15	20–40	25–45	18–33 (3·2–5·7)	—	15–45	205	
				800	52 (82)	530–560	34–36 (54–57)	9–12	15–30	7–10	5–7 (0·9–1·3)	—	5–10	230	
	OQ & T	—	—	800	52 (82)	600	39 (61)	14	50	—	—	—	—	230	
		—	—	1000	65 (102)	750	49 (76)	10	40	17	13 (2·2)	—	20	280	
	WQ & T	1–4	25–102	800	52 (82)	620–710	40–46 (63–72)	13–21	35–60	50–130	37–96 (6·4–16·6)	—	60–100	230	
				1000	65 (102)	830–920	54–60 (85–94)	9–14	20–45	20–40	15–30 (2·5–5·1)	—	25–80	280	
		6	102–152	800	52 (82)	600–620	39–40 (61–63)	9–13	15–35	15–30	11–22 (1·9–3·8)	—	10–30	230	
1·5% Ni-Cr-Mo	Normalized	—	—	1000	65 (102)	780–850	51–55 (80–87)	9–11	20–30	10	7 (1·3)	—	7–10	280	Earth moving equipment: large track shoes, gears and sprocke Cast bodies, teeth and lips of dipper Crusher rocker arms and heads. Pump casings and impellers. Large gear wheels of power plant anc cement mills. Steel mill crane hooks and tongs. Mining machinery. Forging hammer strikers and bolsters Roughing rolls. Marine mooring chain swivels and hc Precision cast parts requiring high strength and ease of heat treatment (i.e., normalize and temper).
	N & T	—	—	800	52 (82)	560–630	36–41 (57–64)	12–16	30–45	30	22 (3·8)	—	30	230	
		—	—	1000	65 (102)	780–850	51–55 (80–87)	9–12	20–30	12	9 (1·5)	—	10	260	
	OQ & T	4	102	740	48 (75)	550	36 (56)	19	50	—	—	—	—	215	
		1–2½	25–64	800	52 (82)	620–670	40–43 (63–68)	12–23	30–65	60–85	44–63 (7·6–10·8)	−30 to −80	75–100	230	
		1¼	32	1000	65 (102)	830–890	54–58 (85–91)	9–15	20–40	25–45	18–33 (3·2–5·7)	−50	35–95	280	
		—	—	1100	71 (112)	940–1000	61–65 (96–102)	8–11	15–35	15–35	11–26 (1·9–4·5)	—	20–90	310	
2·5% Ni-Cr-Mo	OQ & T	4	102	850	55	680	44 (69)	18	50	—	—	—	—	245	High tensile castings of all types. Earth moving ripper arms, Walking drag-line feet. Ore crusher roll shells Pulp crushing cones. Hydraulic cylin Steelworks converter barrel rings, railway bogey frames and couplings. Aircraft wing hinge fittings Mine roof supports and mining-mact drum barrel castings
		1–2¼	25–57	900	58 (92)	740–790	48–51 (75–81)	12–22	30–50	55–70	41–52 (7·0–8·9)	−115	95–100	260	
		1¼	32	1000	65 (102)	840–900	54–58 (86–92)	10–17	25–45	40–50	30–37 (3·8–6·4)	−95	85–100	280	
		—	—	1100	71 (112)	950–1000	62–65 (97–102)	8–13	20–35	27–38	20–28 (3·4–4·8)	—	50–100	310	
		1¼	32	1200	78 (122)	1050–1100	68–71 (107–112)	6–11	15–30	18–28	13–21 (2·3–3·6)	−70	40–100	335	
3·5% Ni-Cr-Mo	OQ & T	1¼	32	930–950	60–62 (95–97)	790–840	51–54 (81–86)	15–21	30–45	45–60	33–44 (5·7–7·6)	−120	80–100	265–270	High tensile and/or heavy section engineering castings. Earth boring machine parts. Precision cast electrical contact breaker parts. Large gears for dredges. etc
		4	102	970	63 (99)	830	54 (85)	13	35	—	—	—	—	275	
		—	—	1000	65 (102)	840–900	54–58 (86–92)	12–18	25–40	40–50	30–37 (5·1–6·4)	—	80–100	280	
		1¼	32	1100	71 (112)	950–1000	62–65 (97–102)	8–15	20–35	30–40	22–30 (3·8–5·1)	−90	70–100	310	
				1200–1250	78–81 (122–127)	1050–1140	68–74 (107–116)	6–10	15–25	18–25	13–18 (2·3–3·2)	−60	45–100	335–345	

(1) Ranges of values are given where data are available for a number of castings; single values are based on more limited information and be may related to a single melt.

** Other values converted from this unit.*

(2) FATT—Fracture appearance transition temperature derived from impact tests.

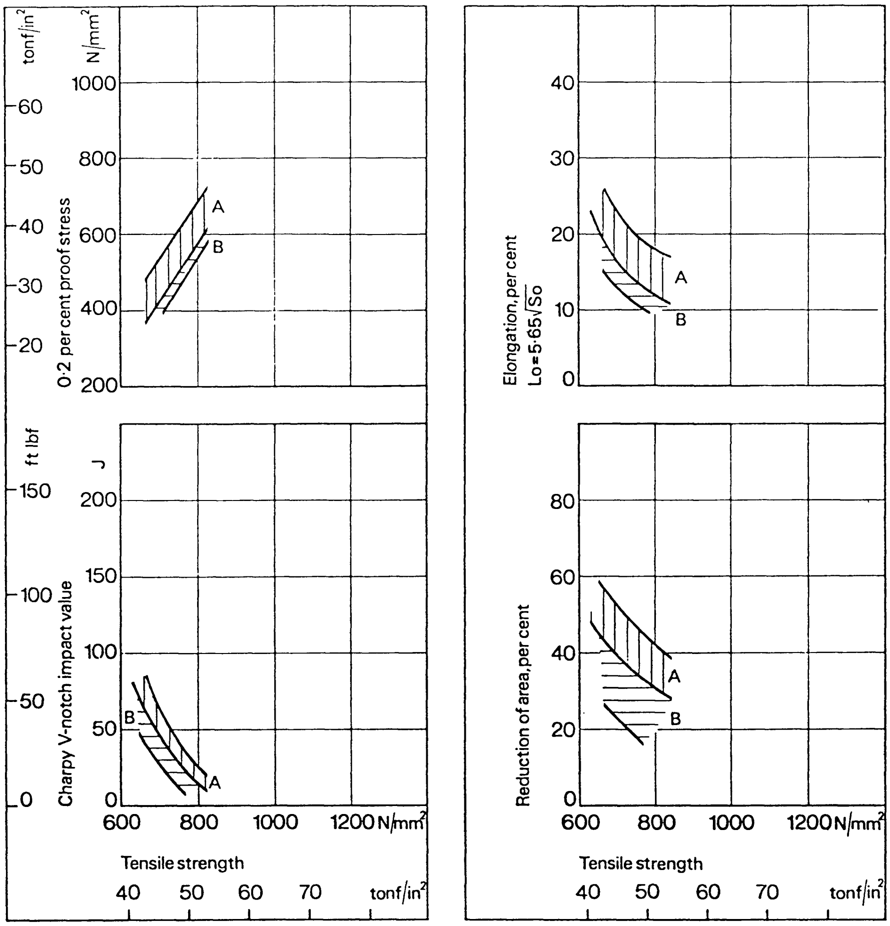


Figure 10. *Cast 0·6 per cent Ni-Cr-Mc steel; normalized and tempered.*

Effect of tensile strength and sectior thickness on proof stress, ductility anc Charpy V-notch impact value.

A – 25 to 100 mm (1–4 in.) section thickness
B – 100 to 150 mm (4–6in.) section thickness

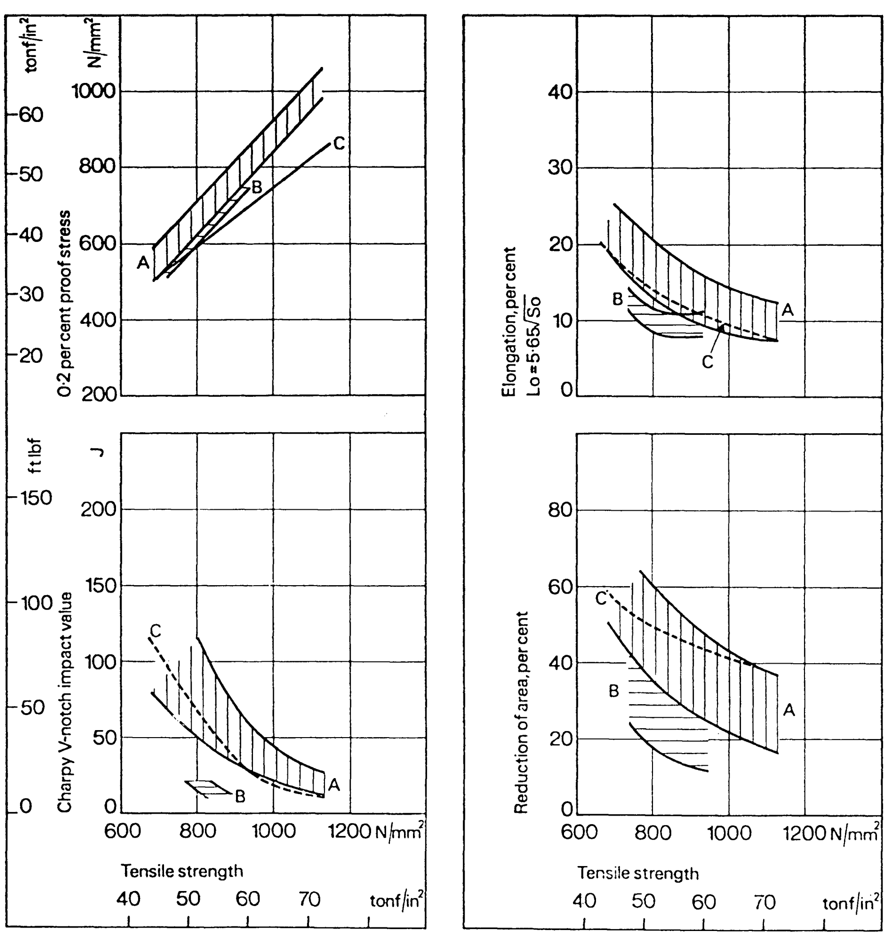


Figure 11. *Cast 0·6 per cent Ni-Cr-Mc steel; oil- or water-quenched anc tempered.*

Effect of tensile strength and sectioı thickness (where known) on proo stress, ductility and Charpy V-notcl impact value.

A – Water quenched and tempered; 25–100 mm (1–4 in. section thickness
B – Water quenched and tempered; 150 mm (6 in.) section thickness
C – Oil quenched and tempered; single melt

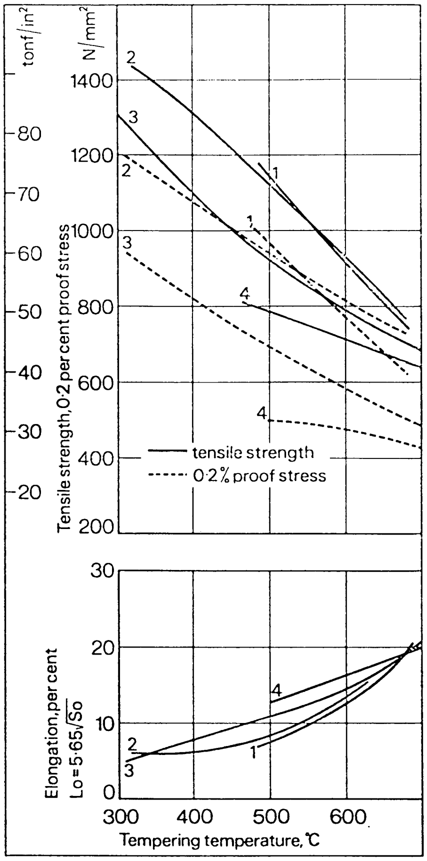


Figure 12. *0·6 per cent Ni-Cr-Mo steel.*

Effect of tempering on the tensile properties of quenched or normalized castings.

1. Steel A, water quenched and tempered
2. Steel B, water quenched and tempered
3. Steel C, oil quenched and tempered
4. Steel C, normalized and tempered

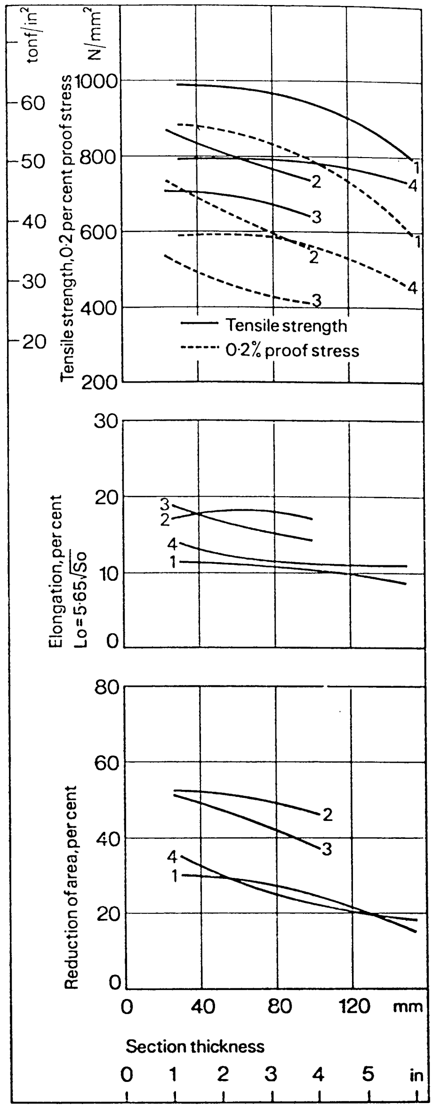


Figure 13. *Cast 0·6 per cent Ni-Cr-Mo steel.*

Effect of section thickness on representative tensile properties after various heat treatments.

1. Steel D, water quenched and tempered
2. Steel E, water quenched and tempered
3. Steel E, normalized and tempered
4. Steel F, normalized and tempered

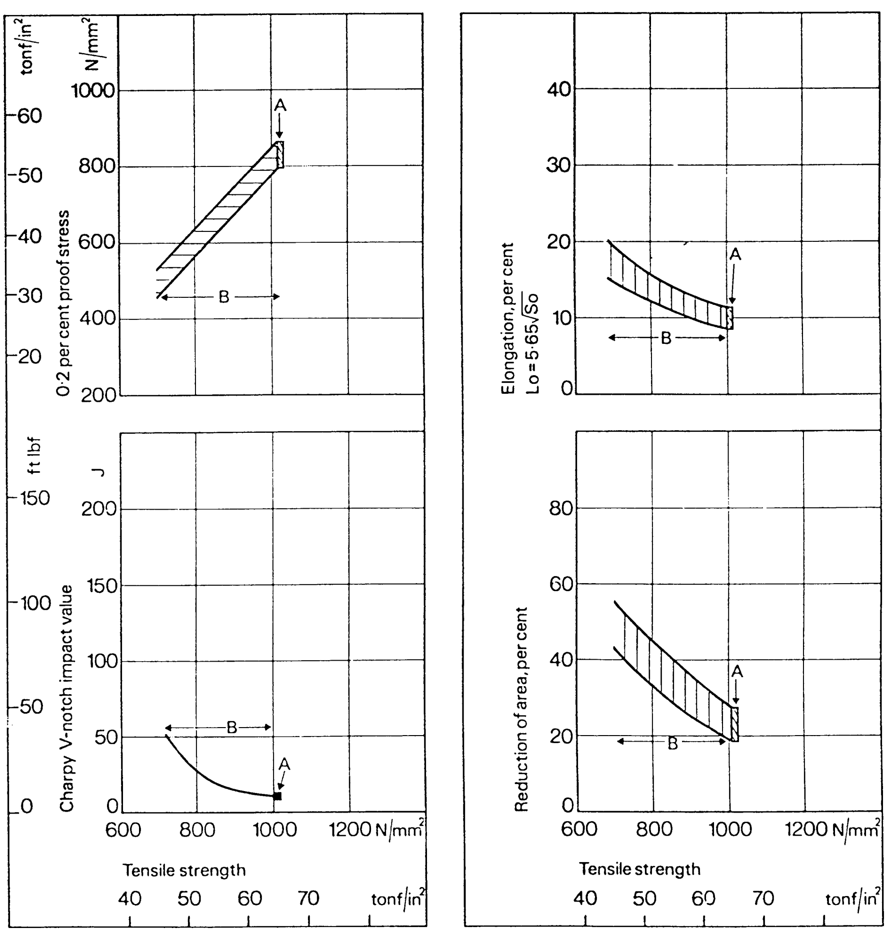


Figure 14. *Cast 1·5 per cent Ni-Cr-Mo steel; A – normalized, B – normalized and tempered.*

Effect of tensile strength on representative values of proof stress, ductility and Charpy V-notch impact energy.

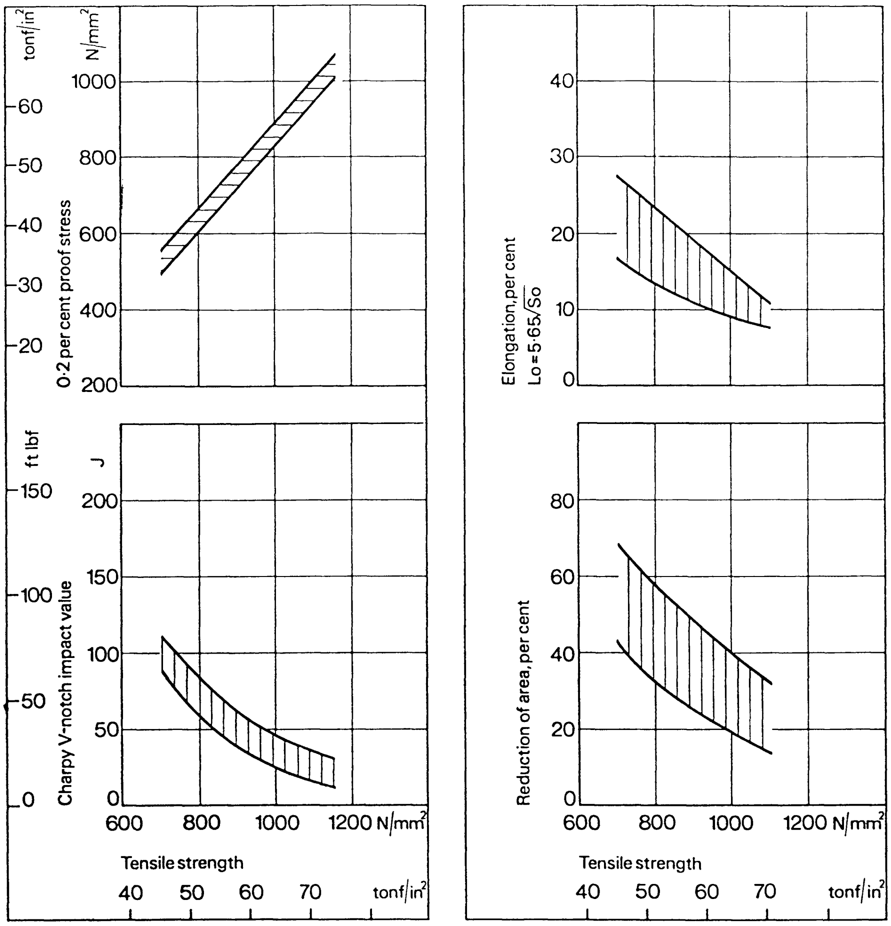
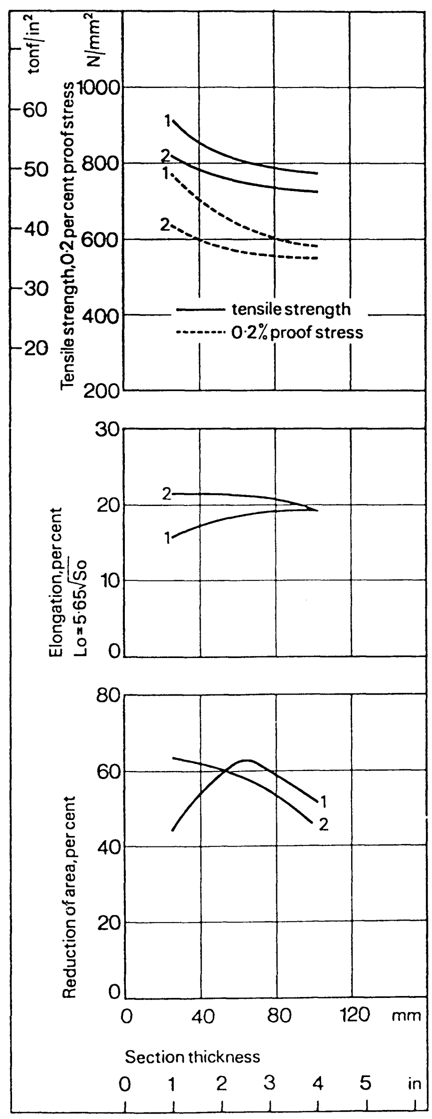


Figure 15. *Cast 1·5 per cent Ni-Cr-Mo steel; oil quenched and tempered. Effect of tensile strength on representative values of proof stress, ductility and Charpy V-notch impact energy.*

Figure 17. *Cast 1·5 per cent Ni-Cr-Mo steel; oil quenched and tempered. Effect of section thickness on representative tensile properties of two steels.*



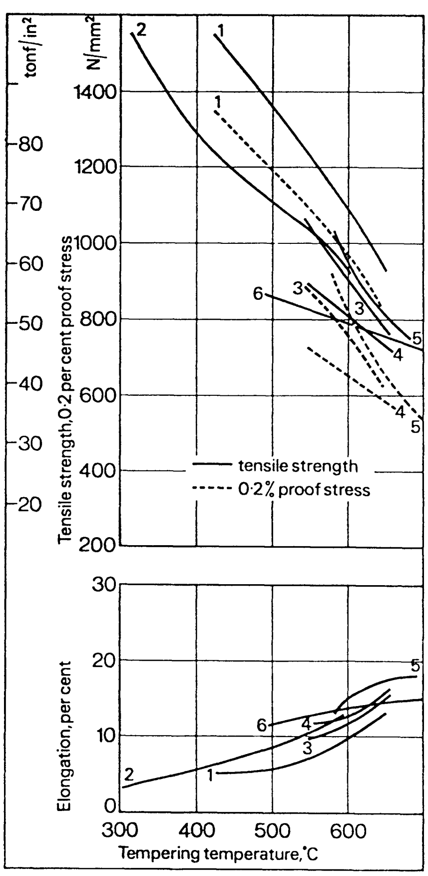


Figure 16. *1·5 per cent Ni-Cr-Mo steel.*
Effect of tempering on the tensile properties of oil-quenched or normalized castings.

Steels 1 to 5 – oil quenched and tempered
Steel 6 – normalized and tempered

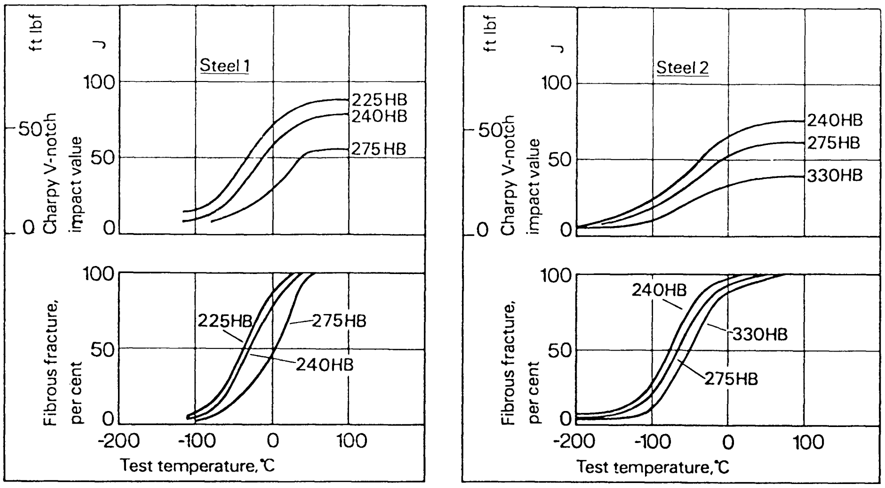


Figure 18. *1·5 per cent Ni-Cr-Mo steel; oil quenched and tempered to various Brinell hardness values.*

Variation of Charpy V-notch impact value and per cent fibrous fracture with test temperature. Typical values of clover leaf castings of two steels, 32 mm (1¼ in.) diameter leaf section size.

***Steel 1 composition:** 0·31C, 0·56Mn, 1·35Ni, 0·80Cr, 0·32Mo*

***Steel 2 composition:** 0·35C, 0·60Mn, 1·90Ni, 0·82Cr, 0·34Mo*

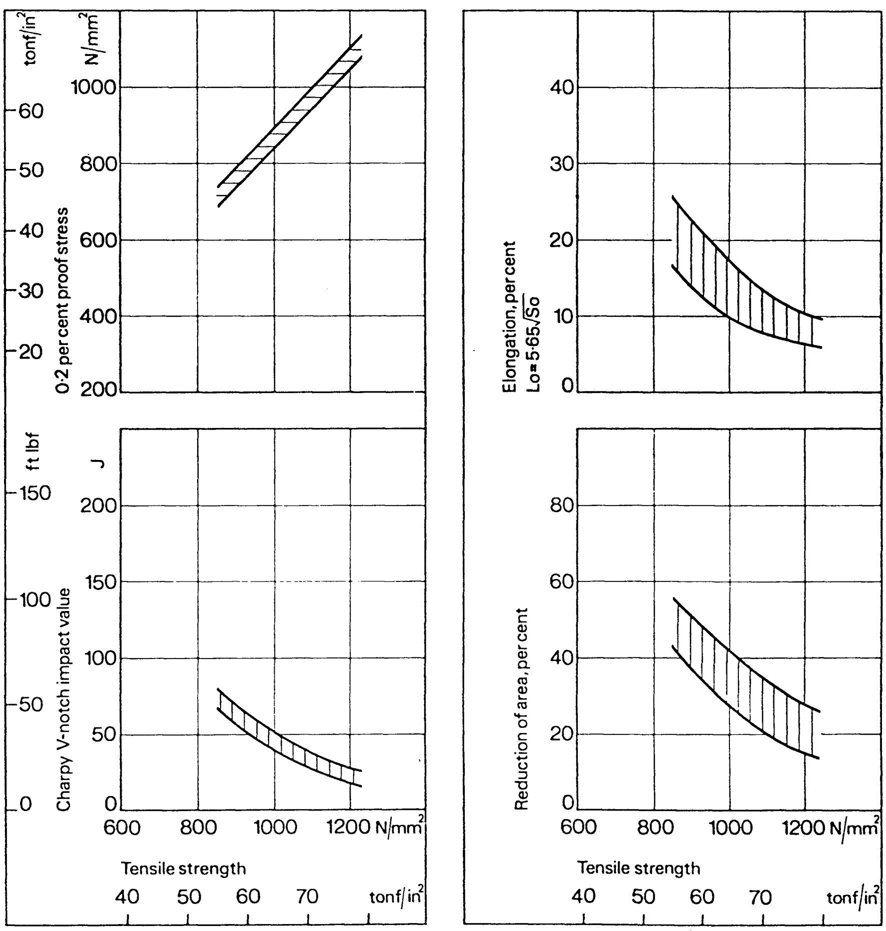


Figure 19. *Cast 2·5 per cent Ni-Cr-Mo steel; oil quenched and tempered.*

Effect of tensile strength on representative values of proof stress, ductility and Charpy V-notch impact energy.

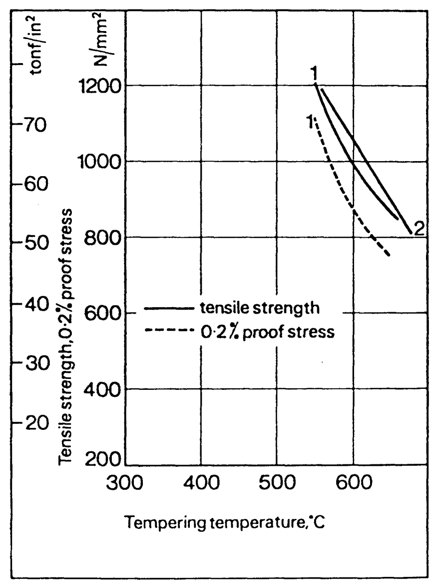


Figure 20. *Cast 2·5 per cent Ni-Cr-Mo steel; oil quenched and tempered.*

Effect of tempering on tensile strength and proof stress of two representative steels.

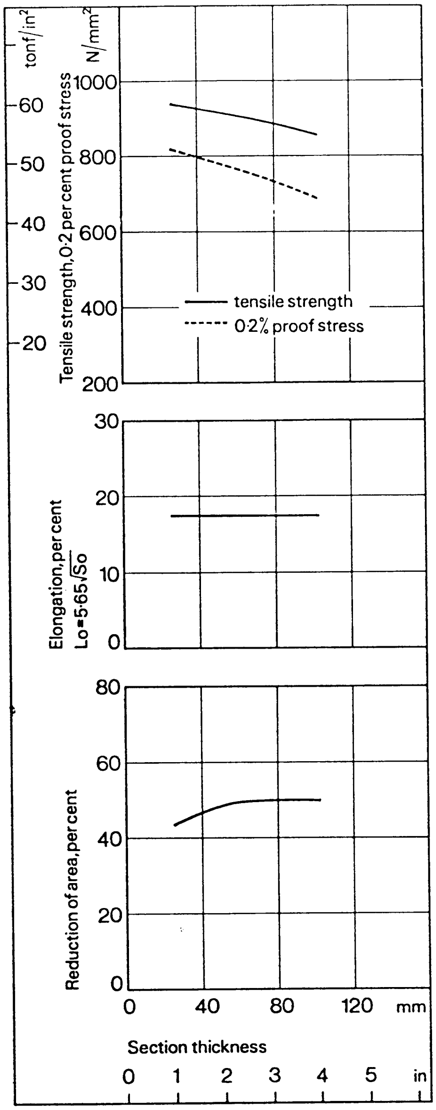


Figure 21. *Cast 2·5 per cent Ni-Cr-Mo steel; oil quenched and tempered.*
Effect of section thickness on representative tensile properties.

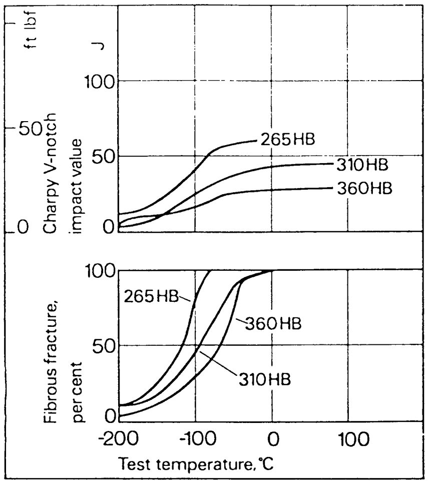


Figure 22. *2·5 per cent Ni-Cr-Mo steel; oil quenched and tempered to various Brinell hardness values.*
Variation of Charpy V-notch impact value and per cent fibrous fracture with test temperature. Typical values of clover leaf castings, 32 mm (1¼ in.) diameter leaf section size.

Steel composition 0.37C, 0.65Mn, 2.60Ni, 0.70Cr, 0.52Mo

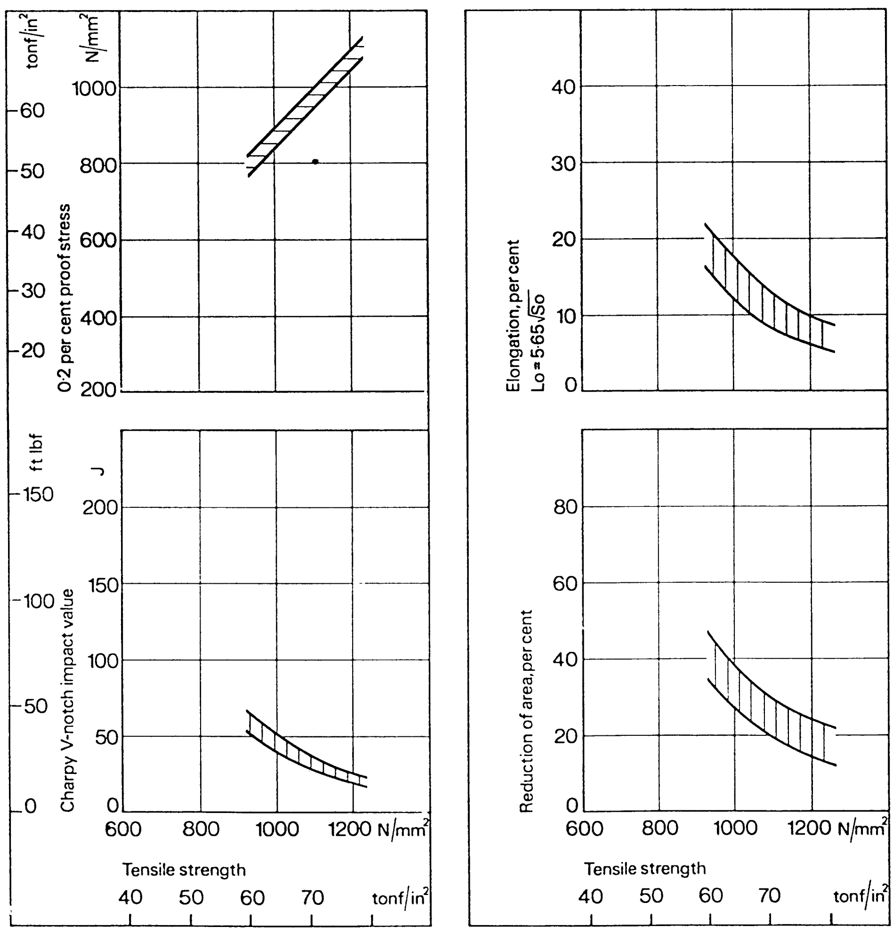


Figure 23. *Cast 3·5 per cent Ni-Cr-Mo steel; oil quenched and tempered.*
Effect of tensile strength on representative values of proof stress, ductility and Charpy V-notch impact energy.

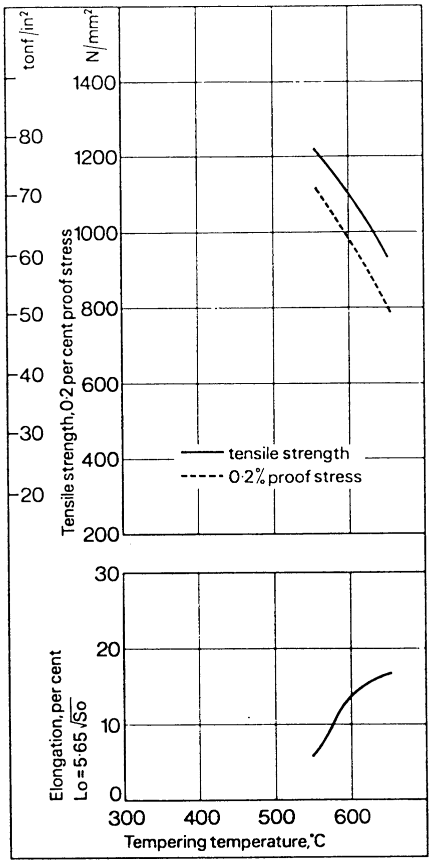


Figure 24. *Cast 3·5 per cent Ni-Cr-Mo steel; oil quenched and tempered.*
Effect of tempering on the tensile properties of a representative steel.

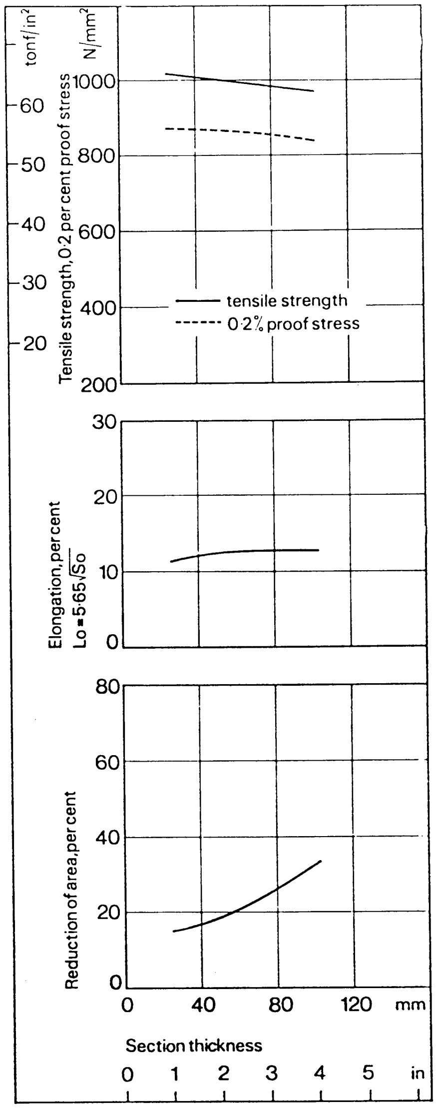


Figure 25. *Cast 3·5 per cent Ni-Cr-Mo steel; oil quenched and tempered.*
Effect of section thickness on representative tensile properties.

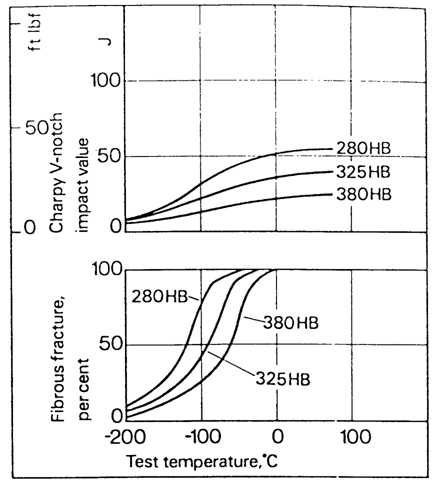


Figure 26. *3·5 per cent Ni-Cr-Mo steel; oil quenched and tempered to various Brinell hardness values.*
Variation of Charpy V-notch impact value and per cent fibrous fracture with test temperature. Typical values of clover leaf castings, 32 mm (1¼ in.) diameter leaf section size.

Steel composition 0.40C, 0.56Mn, 3.20Ni, 1.10Cr, 0.58Mo

Location of data

		UK	France	Germany	Austria	Italy	India	USA
Specifications relating to use of nickel alloy cast steels	Table	1	1	1	1	1	1	1

		Steel type			
		0·6% Ni-Cr-Mo	1·5% Ni-Cr-Mo	2·5% Ni-Cr-Mo	3·5% Ni-Cr-Mo
Composition ranges of commercial grades	Table	2	2	2	2
Physical properties	Table	4	4	4	4
Mechanical Properties Tensile and impact	Figure	10, 11	14, 15	19	23
Brinell hardness/tensile strength relationship	Figure	4	4	4	4
Effects of tempering on tensile properties	Figure	12	16	20	24
Effects of section size on tensile properties	Figure	13	17	21	25
Impact energy value/per cent fibrous fracture/tensile strength relationships	Figure	2	2	2	2
Impact transition curves	Figure	—	18	22	26
Fracture toughness, K_{1c}	Figure	—	1	—	—
Fatigue properties	Table	3	3	—	—
	Figure	5	5	5	5
Effects of section size on fatigue properties	Figure	7, 8, 9	—	—	—
Summary of typical mechanical properties	Table	5	5	5	5

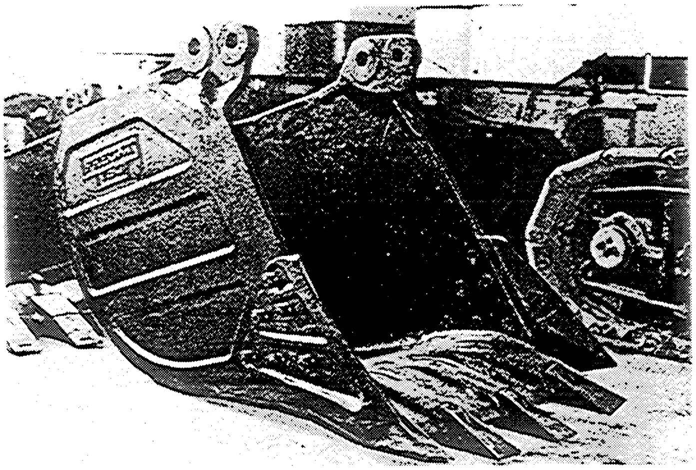


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Figure 27. *750 litre ($\frac{7}{8}$ c. yard) drag-shovel bucket cast in 0·5 per cent Ni-Cr-Mo steel.*
(Courtesy of Priestman Brothers Limited, Hull, England).

Figure 28. *Combined double reduction gear unit and pinion housing (shown with covers removed) fitted with 1·5 per cent Ni-Cr-Mo cast steel gears. (Courtesy of Power Plant Gears Limited, West Drayton, England).*

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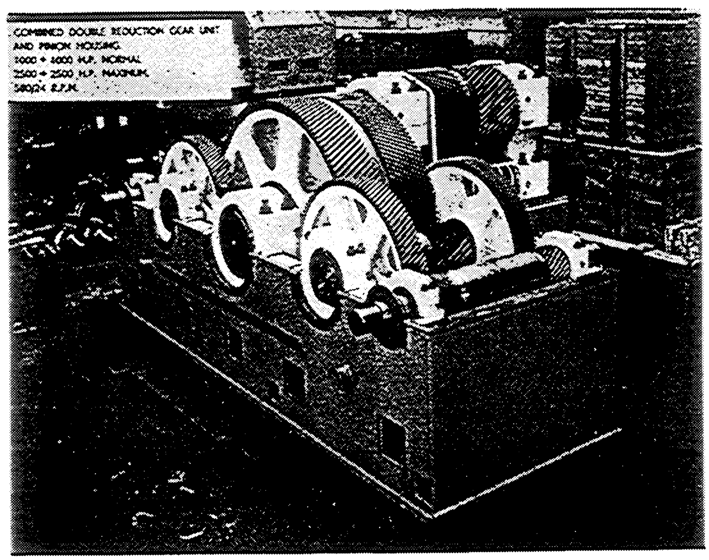

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Figure 29 & 30. *Drilling machine (left) for piles of 600 to 1250 mm (2 to 4 ft) diameter contains many components (above) of cast 35 NCD4 steel (3·5 per cent Ni-Cr-Mo).*
(Courtesy of Acieries de Gennevilliers, Gennevilliers, France).

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Figure 31. *The clevis which fastens the ripper shank to the crossbeam of this tractor is cast in 0·5 per cent Ni-Cr-Mo steel.*
(Courtesy of Caterpillar Tractor Co. Limited, Glasgow, Scotland).

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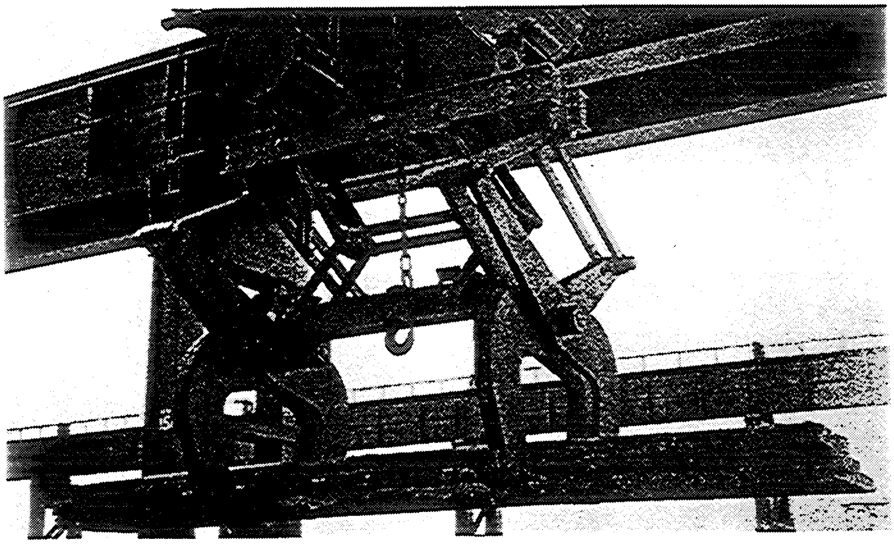

Figure 32. *Steel mill slab handling tongs. The main limbs are flat castings in 1·5 per cent Ni-Cr-Mo steel to British Standard 1458–Grade A. The 'points' are fabricated from wrought steel and are hard-faced.*
(Courtesy of British Steel Corporation, Spencer Works, S. Wales).

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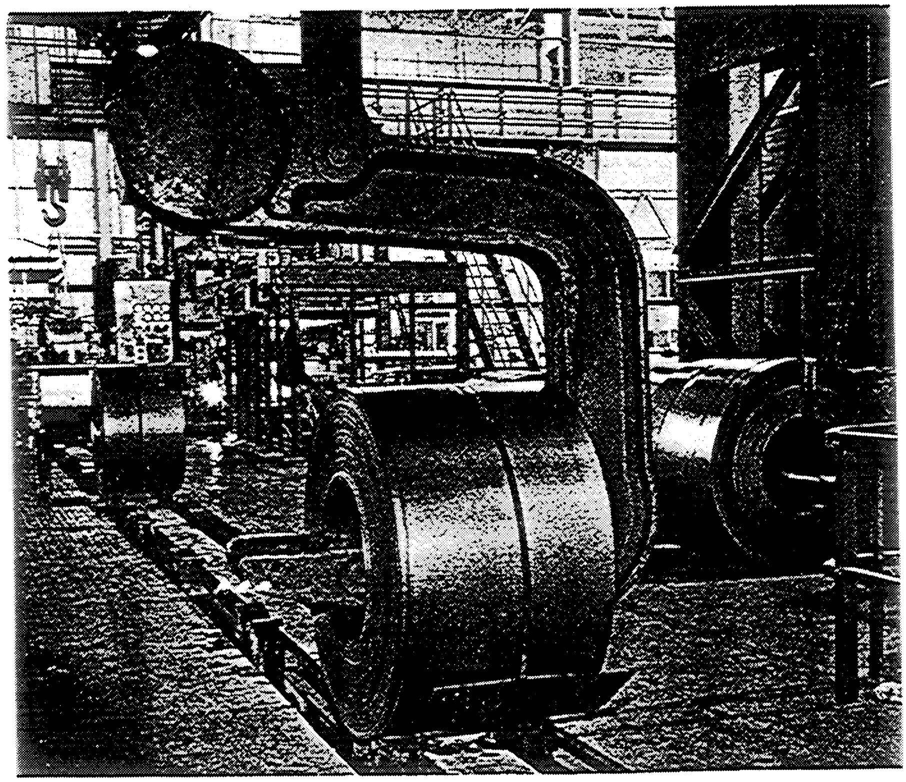

Figure 33. *This large 'C' hook handling coils of steel strip is cast in 1·5 per cent Ni-Cr-Mo steel to British Standard 1458–Grade B.*
(Courtesy of British Steel Corporation, Spencer Works, S. Wales).

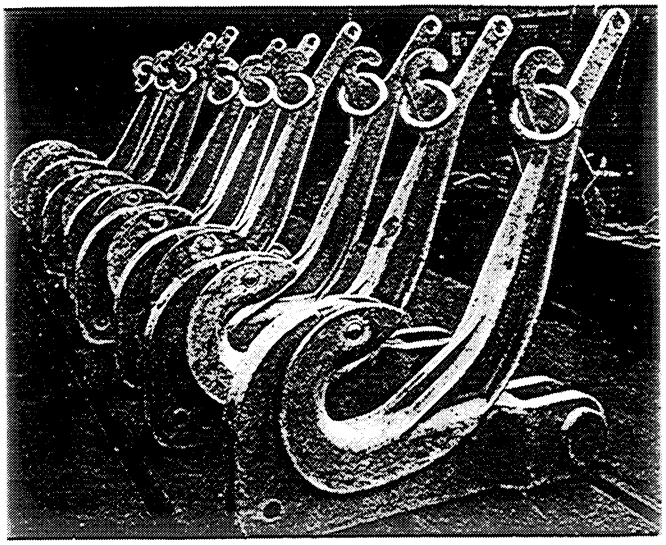

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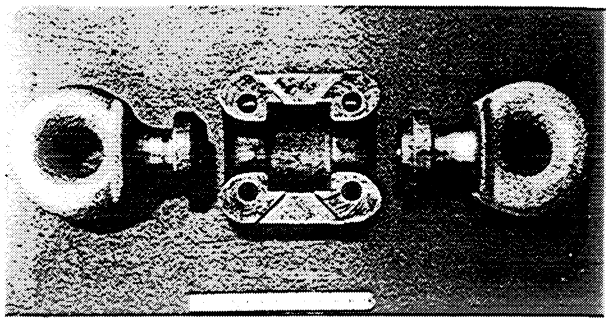
Figure 34. *Quick-release hooks for ships' mooring buoys, cast in 1·5 per cent Ni-Cr-Mo steel to British Standard 1458–Grade A.*
(Courtesy of Brown, Lennox & Company Limited, Pontypridd, Wales).

Figure 35. *Component parts of a box-type swivel for ships' gear and moorings. 1·5 per cent Ni-Cr-Mo cast steel eyes provide the extra strength required in the narrow section where the eye fits into the box.*
(Courtesy of Brown, Lennox & Company Limited, Pontypridd, Wales).



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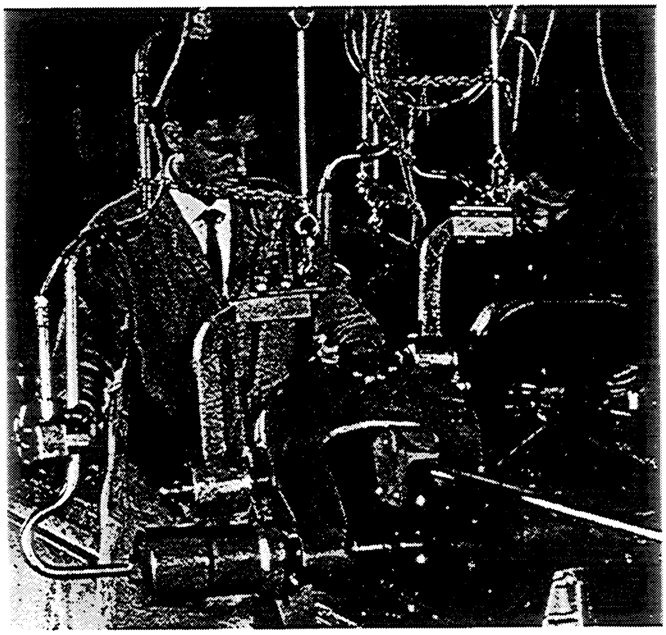

Figure 36. *A 2·5 per cent Ni-Cr-Mo casting is used in this 'C' type rivetting anvil for the fabrication of truck frames.*
(Courtesy of Ford Motor Co. Ltd., Langley, England).

Figure 37. *7-metre (23 ft) diameter barrel ring for a 100-tonne Kaldo steel converter in 2·4 per cent Ni-Cr-Mo cast steel.*
(Courtesy of Fried Krupp Hüttenwerke AG, Bochum).

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