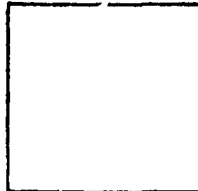


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SOCIETY OF CHEMICAL INDUSTRY
CHEMICAL ENGINEERING GROUP

MODERN CAST IRONS IN CHEMICAL
ENGINEERING

By J. G. PEARCE, M.Sc., F.Inst.P., M.I.E.E.
(Director of the British Cast Iron Research Association)

*Paper to be read at a Meeting of the Chemical Engineering Group to be held in the Rooms of the Chemical Society,
Burlington House, London, W.1, on Friday, November 9, 1934, at 8 p.m.*

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MODERN CAST IRONS IN CHEMICAL ENGINEERING

By J. G. PEARCE, M.Sc., F.Inst.P., M.I.E.E.*

INTRODUCTION

Any consideration of modern cast irons in chemical engineering should strictly be prefaced by a definition of cast iron and also by a definition of the chemical industry, and neither can be put into clearly marked categories. Metallurgically, an iron-carbon alloy is regarded as a cast iron when its carbon content is above about 1.8%, and as a steel when the carbon is below. The presence of other elements, however, alters this figure, and some materials, such as the high-chromium cast irons, are true cast irons although their carbon content is very small. Cast irons usually contain free graphite, but this is not necessarily true of the white cast irons, and graphite is occasionally found in the steels. A convenient definition avoids reference to metallurgical considerations and considers cast irons as irons capable of being cast in and with the ordinary resources of an ironfoundry. In the present paper the steels, cast or wrought, will not be considered. While the chemical industry is commonly understood to cover the manufacture of heavy chemicals, acids, alkalis, and salts, there are many other branches, based on chemical reactions, such as the manufacture of dyestuffs, explosives, fine chemicals, drugs, food, leather, glass, paper, rayon, soap, gas, the refining of oils, the distillation of coals, and so on, to which many of the considerations now advanced will apply. Chemical engineering is called into play when these commodities are manufactured or treated on a large scale, and it is under these conditions that it is necessary to consider how to make the best use of such a cheap and universal material as cast iron.

MECHANICAL PROPERTIES

The chemical engineer, like the mechanical and electrical engineer, is interested in the purely mechanical properties of cast irons used for structural purposes. There has, during the past 15 years, been marked improvement in this respect. In particular there has been an improvement in soundness. The specific strength of a casting or test bar is of little avail if the continuity of the main structure is interrupted at critical points by gas holes, draws, and shrinkage cavities. The greater freedom from such defects may be attributed in part to better melting methods, and in part to better moulding and pouring technique. The density of the metal is thus more uniform. In general, however, defects of this character are less damaging to mechanical than

to chemical or thermal resistance. Small blow-holes seldom appear to reduce the mechanical strength of test pieces, and it has been shown¹ that cast iron is not only relatively very satisfactory in fatigue, having an endurance ratio not far short of that of wrought iron and steel, and improving markedly by understressing, but is not so susceptible as they are to the presence of notches, holes, and other effects which normally localize and intensify stress in fatigue. Cast irons, in fact, behave as if they possessed a measure of ductility which is not shown by the conventional elongation under tensile, but which enables them to adjust themselves to stress.

Modern cast irons are also much more uniform in structure than their predecessors. Iron will normally take up carbon to the eutectic value of 4.3%. This figure is lowered by the presence of other elements normally found in cast iron, notably silicon and phosphorus. Thus an iron containing 2% silicon and 1% phosphorus will have a eutectic carbon value of 3.4%. With the aid of silicon, which breaks down or graphitizes the iron carbide which this carbon normally forms, the bulk of the carbide can be converted to iron and graphite, a process that is also facilitated by slow cooling. The founder uses silicon, suited to the section to be cast, to produce a grey and machinable casting from what would otherwise be white iron. The carbon remaining in combination is in the form of iron carbide (cementite), existing with iron (ferrite) as the finely laminated duplex-structure pearlite. An iron or steel is usually fully pearlitic with 0.9% carbon in the combined form. Combined carbon in greater quantity exists as massive iron carbide or cementite, which is normally unmachinable, and arises, unless deliberately wanted, from too low silicon or too rapid cooling. Conversely, with too high silicon or too slow cooling, the pearlite carbide breaks down to graphite and iron (ferrite). Castings formerly tended to be mixed structures of graphite, pearlite, and ferrite. In recent years however, by closer metallurgical control, a more uniform structure can be obtained, consisting of pearlite and graphite. Fig. 1 shows the structure of an iron of mixed ferrite and pearlite structure. Fig. 2 shows a similar iron, all pearlitic, also made for the chemical industry. Fig. 1 contained some phosphorus, visible as phosphide eutectic. Fig. 2 is more homogeneous and mechanically stronger than those having mixed structures. If the carbon is over the eutectic value, the graphite is apt to be coarse and diminishes in size and quantity as the carbon falls below the eutectic. In the respects referred to,

* Director, British Cast Iron Research Association.

soundness and homogeneity, it is much more important for the user to choose a good foundry than to set up a specification.

In 1928 the B.S.I. issued a general specification, No. 321, for iron castings, covering two grades, A and C, neither of which has high mechanical strength, 9 to 12 tons per sq. in., but which serve the user of the ordinary types of castings. The testing clauses of this specification are novel, and can and should be applied to any specification for castings of better mechanical quality than are provided for in the specification 321 itself. For straightforward engineering castings, large or small, there is little difficulty in obtaining tensile strengths

elastic modulus in a simple way.³ The Brinell hardness is an occasionally useful figure, but it has no clearly defined relation to mechanical strength of any kind, to resistance to abrasive wear or even to machinability, and hence its use is limited. The mechanical strength of ordinary cast iron at atmospheric temperatures is maintained and in many cases increased up to 450° C., and then it falls slowly as temperature is further increased. For data on strength at elevated temperatures and thermal conductivity, papers by Donaldson may be consulted.⁴ To facilitate the production of good castings, it is strongly recommended that designs be discussed with the foundry and pattern shop, or that the founder



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FIG. 1

Cast iron showing pearlite, ferrite, and graphite

of 15 or even 18 tons per sq. in. In general, it suffices to specify mechanical properties, and only in special cases is it necessary to specify composition.

The strength of cast iron is usually obtained in transverse, and the author recommends that this be expressed as a specific rupture stress, calculated from the usual beam formula.² This stress is usually about 1.8 to 2 times the tensile strength. The compression strength is usually about 4 times the tensile. The elastic modulus is not easy to obtain in the ordinary way, as the deflection under load not only increases with but at a greater rate than load—this, indeed, being a valuable feature of cast iron and calculated to enable it to resist shock or impact better than a truly brittle material. The author has suggested a method for obtaining the



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FIG. 2

Cast iron showing pearlite and graphite

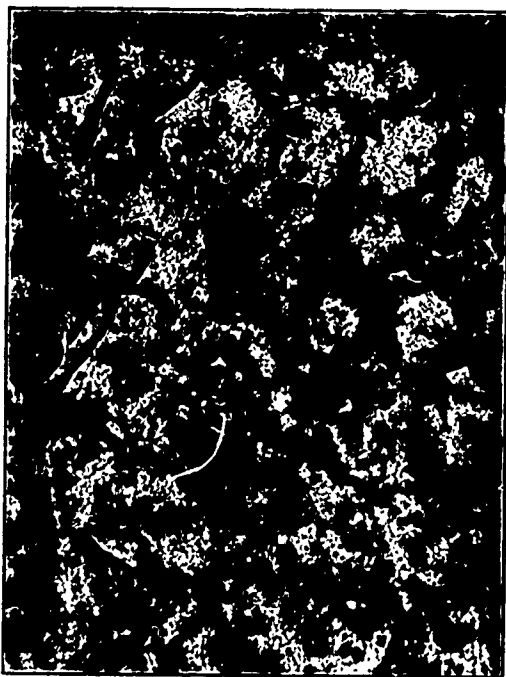
be asked for suggestions which would improve the castability before manufacture.

The most striking advances in the production of strong irons have come about by reduction of the size and quantity of graphite. To maintain a pearlitic structure, the graphite content can at present be best attained by using a low total carbon. The precise figure required is governed by the silicon content for a given section of casting. Several methods of achieving this are available, but essentially the principle is to cast an iron so that it would be white when poured and then to make it grey by a ladle addition of a graphitizing material. The graphite produced in this way is smaller than that normally attained. One such process, due to and patented by the International Nickel Co., Ltd.,

makes use of nickel and ferro-silicon as a ladle addition, and such an iron, commercially made, gave the following results on test:

Analysis	
	%
Total carbon	2.70
Silicon	1.57
Manganese	0.98
Sulphur	0.13
Phosphorus	0.16
Nickel	0.95
Mechanical tests on 1.2-in. bar	
Tensile strength	28.7 tons/sq. in.
Transverse strength	50.0 tons/sq. in.
Deflection, 18-in. centres	0.35 in.
Brinell hardness	277
Impact strength	2886 blows
Transverse strength	50.0 ..

The impact strength is 10 times that required to break an iron of cylinder quality, say 15 tons per sq. in. tensile. It is taken on a Stanton-type test piece with rounded notch. Fig. 3 gives the structure, pearlite-graphite, of this high-quality iron. Another process employs calcium silicide as the ladle addition, and the metal is known as Meehanite. A tensile strength of 24 tons per sq. in. with a Brinell hardness of 227 has been recently published for this material.



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FIG. 3

High duty iron showing pearlite and graphite

A word of caution is required about specifying these high-duty irons. They are more difficult to cast, for they have a higher melting temperature, a shorter fluid range, and greater shrinkage than

ordinary cast irons, and it does not follow that any and every casting can be made in them. The necessity for securing varied thicknesses in one piece forms the very *raison d'être* of the average casting, and the design and size often compel the use of a

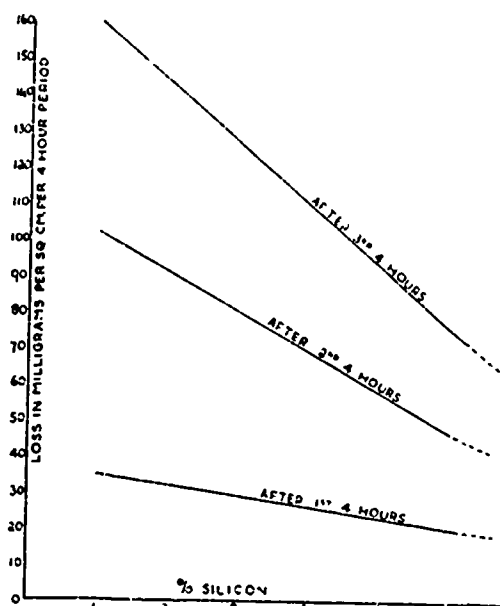


FIG. 4

Effect of silicon on corrosion-resistance in normal H_2SO_4

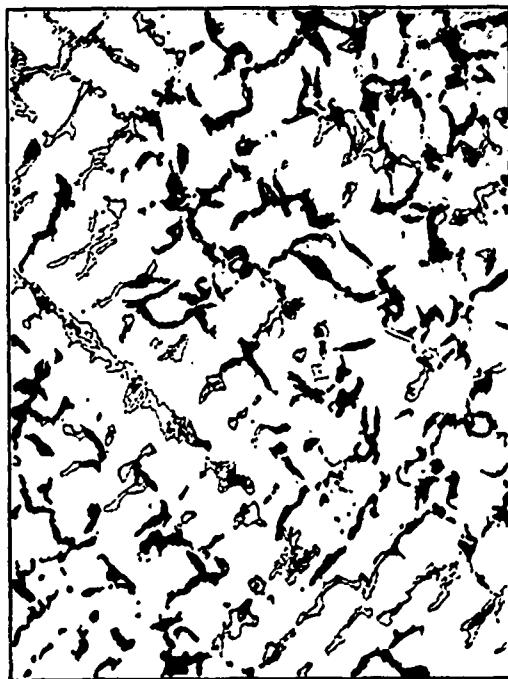
composition permitting a greater degree of castability. Where the high-duty irons can be used, castings should be designed so that the fullest advantage is taken of the higher specific strength.

Space does not permit more than passing reference to heat-treated cast irons, a process that is extending its application: annealing is frequently used, both to relieve casting stresses or to soften an unduly hard or white iron. In the production of malleable iron, white castings are annealed for a prolonged period. For malleable cast irons two B.S.I. specifications are now available, 309/1927 for whiteheart and 310/1927 for blackheart.

The question of abrasive wear is important. So far as lubricated conditions (as in engine cylinders) are concerned, it has been shown³ that corrosion is a material factor in abrasive wear. Even under dry conditions the abraded material is so fine that it readily oxidizes and remains on the wearing surface as a grinding paste. For best resistance to dry abrasive wear, it is generally accepted that the wearing parts should be fully pearlitic with a minimum difference in Brinell hardness. Wear increases as this difference increases. For crushing or grinding, special alloys are required. A recent development in hardening the surface of cast iron is that of nitriding, which enables Brinell hardness figures up to 900 to be obtained. Without going into the question of graphite size too closely, there are, broadly, three

sizes to be distinguished. The coarse graphite illustrated in Fig. 1 may be contrasted with the extremely fine or supercooled type of graphite in Fig. 6, for although this illustration refers to a high silicon iron, the supercooled type of graphite can sometimes be seen in the normal cast irons, although it is not common. Intermediate between these two is the size approximately shown in Fig. 3. These illustrations are only approximate because graphite size will vary with rate of cooling and other factors as well as composition, and differ in different parts of the same casting. From the point of view of mechanical strength and abrasive wear, however, this intermediate size is most satisfactory, and we shall see that the same remark applies to corrosion resistance.

Striking improvements in soundness, uniformity of strength and structure as between thick and thin sections and as between the centre and edge of a thick section, and increased strengths have been obtained by the use of alloy additions to cast iron, particularly nickel, chromium, and molybdenum in small quantities. The irons under these conditions remain pearlitic. The compositions are balanced, modifications being made to the basis composition to suit the additions. More extended reference to



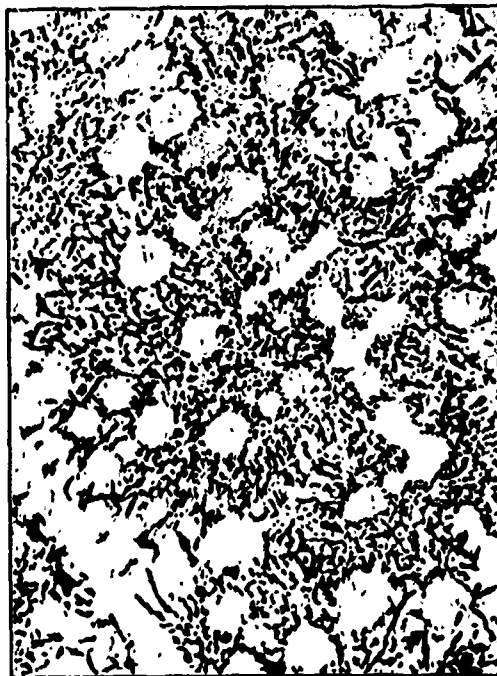
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FIG. 5

Niresist austenitic cast iron

the effect of such additions on corrosion and heat-resistance is made below. Broadly speaking, anything which contributes to the strength, soundness, and homogeneity of cast iron also improves its

resistance to corrosion and heat, but there are sufficient exceptions to this general rule to make it impossible to treat these properties in one group. Some measure of repetition is therefore unavoidable.



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FIG. 6

Silal heat-resisting cast iron

CORROSION RESISTANCE

All ferrous materials are liable to corrode, but discussion of this point often obscures the fact that cast iron normally offers excellent resistance compared with other ferrous materials not specifically manufactured to resist corrosion. In general, where cast iron is not at least as good, it offers better resistance than steel, as, for instance, to dilute and strong acids and alkalis. Cast-iron pipes have been known to last over a century, and the author was once asked to provide data for an iron which would give a longer life than one which, after eighty years' working as a pipe line, under pressure and buried in soil, showed occasional patches of corrosion. Those interested in the general question can with advantage consult the work of Friend.⁶ For 18 years past a Committee of the Institution of Civil Engineers has been studying the deterioration of structures in sea water. Two samples, of hot-blast and cold-blast iron respectively, were included in the tests, and the results bear out the remarkable resistance of cast iron, and confirm the general conclusion given above. An elaborate series of studies of soil corrosion has been made over a period of 10 years by the Bureau of Standards, from which again cast iron emerges very satisfactorily. Cast iron sometimes

corrodes under circumstances which prevent the removal of oxidation products. The ferrite and pearlite are dissolved, leaving the oxidation products in place held together by interlacing strands of graphite, the shape being retained when other ferrous metals would have completely disintegrated. The metal under these conditions can be readily cut with a knife, and is sometimes said to have suffered from "graphititis," or graphitic decay.

The resistance of cast iron to acids and alkalis is now well known, both from laboratory tests and large-scale trials, and it is not necessary to recapitulate the data here. Corrosion tests are made in many laboratories, but it is well known that results are not always borne out in large-scale operation. The author uses simple corrosion tests, complete immersion, partial immersion, or alternate wet and dry tests, mainly as a means of selecting materials which would repay further tests on a larger scale. In chemical work the presence of even slight impurities in the medium, or differences in concentration, will cause marked differences in behaviour in large-scale as compared with laboratory operation. Simple exploratory tests could with advantage be standardized, leaving other tests to imitate practical conditions as closely as possible. The difficulty of absorbing a multitude of corrosion results, involving different concentrations, temperatures, and media, is diminished in Germany by grouping results as follows, a practice which might well be generally adopted, although as yet differences in test procedure makes comparison difficult between different laboratories.

Loss in weight, gm./sq. metre/hour	Resistance
Below 0.1 ...	Completely resistant
0.1 to 1.0	Satisfactorily resistant
1.0 to 3.0	Fairly resistant
3.0 to 10.0	Slightly resistant
Above 10.0	Non-resistant

Soundness and homogeneity of the casting are of great importance in increasing resistance to both corrosive and thermal attack, as the graphite cavities present channels for the admission of the corrosive and heating media. The extremely fine form of graphite (Fig. 6) seems, at any rate in some media, more liable to corrosion than flake graphite, although extremely coarse graphite is not recommended.

The influence of elements of composition cannot be simply stated, because a number of elements exert more than one effect. Thus silicon softens the metal by virtue of its effect in breaking down cementite to ferrite and graphite, so that increasing silicon is accompanied usually by increasing graphite. Intrinsically however, silicon hardens and embrittles the metal, as is seen most completely in the case of the high silicon irons. C. Rowley, in the laboratories of the British Cast Iron Research Association, has studied the effect of silicon, in samples of which the graphite size was kept reasonably constant. Fig. 4 shows that silicon reduces corrosion against acids, and the curves may be extrapolated to show that the

corrosion is negligible at about 14% silicon, which would be expected. Intrinsically therefore, the element behaves consistently. Silicon appears to diminish corrosion-resistance to alkali, which needs a low carbon, low silicon, low phosphorous material, yet grey and free from carbides. Manganese and sulphur do not have a very great effect on corrosion of cast iron in the amounts normally present. The increased use of scrap has tended to raise the amount of sulphur normally present, and by the use of soda ash it has been found possible to reduce the amount of sulphur by, roughly, 50%. Manganese and sulphur exist mainly as an inclusion of manganese sulphide. Phosphorus does not materially affect the corrosion-resistance towards acids, but the resistance is lowered in the presence of alkalis, and hence a hematite iron is preferred for caustic pots.

Marked improvement in corrosion-resistance has been found by using low-alloy additions to cast iron, especially nickel. Used under proper conditions of a balanced composition, the silicon being modified in ratios now well understood by metallurgists, the improvement due to nickel is doubtless brought about in part by increased soundness and homogeneity. Chromium does not of itself improve corrosion-resistance to H_2SO_4 ; in fact, it makes it worse. Nickel and chromium together, however, can be employed in such proportions as to render unnecessary any alteration to the silicon content, and under these conditions there is no objection to the use of chromium. The metal is fully pearlitic. Chromium present in small quantities enters partly into solution and partly forms a carbide. The latter is detrimental to corrosion-resistance.

The figures given below will illustrate the point, although the nickel in the third iron is not quite enough to give a balanced composition. The iron was of good engineering quality, and the test was taken in normal H_2SO_4 .

	Loss in gm. sq. metre/hour
Ordinary iron ...	65
Same with 0.75% chromium	92
Same with 0.8% nickel and 0.5% chromium	42

For applications where strong, machinable irons are required, of greater resistance than normal, these low-alloy irons offer considerable advantage. Perchke and Popova⁷ concluded that for caustic pots irons containing nickel, chromium, or nickel-chromium up to 12% should be used, and regard the presence of nickel as essential. In considering all these additions, increased cost should be considered in relation to increased life.

The acid-resisting high silicon irons have been used for 30 years in the chemical industry. This material is extraordinarily resistant to many acids, alkalis and salts, being perhaps the best all-round acid-resisting ferrous material, but suffers from brittleness, and it is a very difficult material to cast sound. For these reasons many attempts have been made, especially in Germany and U.S.A., to improve it,

but without marked success. The material, in fact, has not undergone substantial change. At the same time, improvements in foundry technique have been made, and the metal is now made more sound than formerly. It is well known that the resistance of the high silicon alloys increases slowly to about 12% silicon, when a sudden increase takes place, and there does not appear to be any advantage in increasing this figure over about 16%. The castings are usually subjected to a low-temperature heat-treatment before use. For reasons which will be apparent later, the high silicon irons also resist heat. Tests on Ironac have shown practically negligible losses after boiling in H_2SO_4 (65% and 20%) and HNO_3 (90% and 20%) at 150°C . for 72 hours, and equally small losses in mixed acid, 65% H_2SO_4 , 2% HNO_3 , and 33% water. Exposure of the same iron, weighing about 80 gm., to H_2SO_4 for 30 days at 15°C . showed a loss of 0.73 mgm. per sq. cm. for 50% H_2SO_4 , 0.68 mg. per sq. cm. for 70% H_2SO_4 , 0.58 mg. per sq. cm. for 70% H_2SO_4 at 120°C .

The latest contribution to the corrosion problem is that of the nickel-bearing austenitic cast irons, of which two are commercially available, Niresist, developed by the International Nickel Co., Ltd., and Nicrosilal, developed and patented (British Patent 378,508) by the British Cast Iron Research Association. These alloys offer great advantages in that they can be made extremely soft (Brinell 120 to 140). They are easily machinable and take a high finish, but are stronger and tougher than the grey iron and harden under cold work. They can be made harder by increasing the chromium contents. They make admirable castings, and have been widely used with marked success. As will be indicated below, they are also highly heat-resistant and non-magnetic, as well as corrosion-resistant. They have a higher coefficient of thermal expansion than ordinary irons, 1.8×10^{-5} compared with 1.4×10^{-5} for pearlitic irons, and a rather lower thermal conductivity, these being governed by the austenitic structure. They have the great advantage of being comparatively ductile, having elongations in the cold of the order of 2% to 4%. They are roughly 2 to 200 times as resistant as ordinary cast iron to corrosion, according to the medium, and compare in resistance with phosphor bronze. They are also considerably more resistant to erosion than ordinary cast irons.

Niresist contains approximately 14% nickel, 6% chromium, and 5% copper. Nicrosilal is a development of the iron Silal referred to below, and contains about 6% silicon, 18% nickel, and 2% chromium. The constituents can be varied in both irons to meet the requirements of particular cases. The carbon content of these alloys varies between 1.8% and 3%.

The following figures, taken in the B.C.I.R.A. laboratories, will give some idea of relative resistances,

	Loss in weight per unit area in unit time		
	$\text{N} \cdot \text{H}_2\text{SO}_4$	$\text{N} \cdot \text{HCl}$	$\text{N} \cdot \text{HNO}_3$
Ordinary grey iron	328	301	218
Hematite	301	253	284
Niresist	2.8	1.5	214
Nicrosilal	1.5	1.5	163

and a good deal of information is now available on this point.

The microstructure is shown in Fig. 5 and is of Niresist.

HEAT RESISTANCE

All irons and steels are liable to oxidation or scaling at elevated temperatures. Cast irons containing no graphite, such as the white irons, behave like the steels, but grey irons, containing graphite, are liable, in addition, to growth, to an actual increase in dimensions. The growth usually takes place in two stages: first, the iron carbide breaks down to iron and graphite, which may involve a 2% increase in volume. Secondly, the iron itself oxidizes, and this causes a still larger volume increase. The mode of breakdown is as follows: Oxidizing gases penetrate the graphite cavities and oxidize the iron in the neighbourhood. The volume increase sets up a stress resulting sooner or later in a fine crack, which opens a further channel to attack. The process continues until the casting is honeycombed with cracks, which appear, for example, on the working face of an ingot mould or retort as crocodile markings. The growth of an iron is greater at a given temperature if the total carbon, and hence the graphite, is greater, and within limits, if the silicon is greater, since it provokes the formation of graphite. Silicon in solution in cast iron, however, intrinsically confers resistance to growth, and this fact was made use of by the B.C.I.R.A. in developing Silal heat-resisting cast iron (British Patent 323,076). This iron usually contains 4% to 6% silicon, and hence contains no carbide to break down. The graphite can be made in a very fine state of division, and the silicon actually makes the body of the metal more resistant to oxidation, and hence growth. Also the silicon raises the critical point of the metal above that of the ordinary cast irons. All pearlitic and ferritic cast irons pass through a critical change at about 760°C ., at which graphite dissolves, followed by a contraction in volume. The metal then becomes austenitic. This change fixes an upper limit of temperature for the use of grey irons. By silicon additions the change can be raised to 1000°C . Nickel, chromium, and copper can be used to depress this temperature to atmospheric, and hence irons austenitic in the cold suffer no change of this kind. As many industrial processes involve heating up to about 700°C ., the effect of silicon in raising the temperature of the critical change, which is accompanied by a volume change, is very important practically.

The microstructure of Silal is shown in Fig. 6, consisting of fine graphite flakes in ferrite. Silal is rather more brittle than ordinary grey irons. It should be noted that the melting point of all these irons, pearlitic or austenitic, is much the same. Aluminium can be and has been used in Silal, but it is found difficult to incorporate aluminium into ferrous castings without loss of mechanical strength, probably due to the ready oxidation of aluminium. From the heat-resisting point of view it is a valuable addition, particularly against sulphur attack. Silal, Nicrosilal, and Niresist retain strengths at high

temperatures to a much greater extent than ordinary cast irons and steels, and are much more rigid. Independent tests have shown that they retain at 800° C. about one-third of their tensile strength at atmospheric temperature. Tests in the B.C.I.R.A. laboratories have shown the rigidity of these irons at 850° C. A high-quality grey cast iron deflected 1.9 in. under load in four days. Silal deflected 0.32 in. and Nicrosilal 0.08 in. under the same conditions.

It will be seen that there are, broadly, two methods of making an iron heat-resistant. It is practicable to postpone carbide breakdown as long as possible by using irons low in silicon and/or carbon, or by using alloy additions of carbide-stabilizing and carbide-forming elements such as chromium. Ultimately, if the silicon and carbon are low enough, or chromium high enough, a white iron is produced. White irons are strongly resistant to heat and are frequently used in practice, but for many purposes their brittleness and lack of machinability are handicaps. The second method is, as in Silal, to arrange for the metal to be ferritic with fine graphite, with a high silicon matrix. Additions which contribute to soundness also contribute to heat-resistance, such as irons in which part of the silicon is replaced by nickel. Thus the low nickel and chromium alloyed irons have a sphere of usefulness for heat as for corrosion-resistance. In ordinary grey irons phosphorus is often present. The hard phosphide eutectic makes the metal more rigid up to about 960° C., when the eutectic melts, causing the metal to collapse. Phosphoric irons should therefore be used well within this temperature.

The austenitic irons Niresist and Nicrosilal are excellent heat-resisters, having, compared with Silal, the added advantages of toughness and ductility as well as greater resistance to scaling and growth. The growth, indeed, of these alloys is almost negligible. When cast in the white state and subjected to a simple short annealing, Nicrosilal has an elongation comparable with that of malleable cast iron. Inglis¹ gives the following summary:

	Temp. at which serious deterioration occurs (growth and scaling)	Temp. at which appreciable scaling occurs	Recommended maximum for practical use
	°C.	°C.	°C.
Ordinary cast iron....	500	500	450
Pearlitic cast iron	650	500	550
1% chromium cast iron	750	550	600
Silal (4-10% Si)....	900	900	750
Nicrosilal and similar high chromium and nickel-chromium cast irons	no change up to 1000	900	950

Finally, it is necessary to refer to the high chromium irons. The iron-chromium alloys up to 13% chromium are very resistant to corrosion and formed the early stainless steels. The addition of carbon, essential in a cast metal, reduces this resistance to

corrosion on account of the carbon forming chromium carbide. This drawback can be overcome by increasing the chromium content, and castable alloys can be made with carbons varying from 1% to 3% with about 35% chromium, all true cast irons. While not so resistant, generally, as the high silicon irons, they do offer better corrosion-resistance than any other type of cast iron, and are also highly resistant to heat up to about 1100° C. The tensile strength is twice that of ordinary grey iron, without elongation and it is maintained up to 500° C. The higher the carbon the harder these alloys become, and for a machinable material should not exceed 1% or thereabouts.

It is now generally accepted, and confirmation has been obtained in this country, in U.S.A. and Germany, that these high chromium irons offer good resistance to sulphur and sulphurous gases, H₂S, SO₂, and SO₃. A recent paper² gives results on resistance of some thirty ferrous materials to gaseous H₂S. A Niresist iron had resistance superior to all other materials tested, except the chrome and chrome-nickel steels. The high chrome irons were not tested. Plain cast iron corroded three to four times as fast.

The variety of working conditions to be met necessitates each case being treated on its merits, and in this connexion members of the B.C.I.R.A. are always able to obtain advice on the most suitable materials to use for a given service.

CONCLUSION

Considerations of space have prevented presentation of more than a small proportion of the data available on cast-iron developments, but it is hoped that the brief survey given above will assist in the better application of cast irons to the chemical industry, both those already well known and the more recent advances.

BIBLIOGRAPHY

- ¹ Moore, Lyon, and Inglis, "Tests of the Fatigue Strength of Cast Iron," Bulletin 164, 1927, University of Illinois Engineering Experiment Station.
- ² Pearce, "The Use and Interpretation of the Transverse Test for Cast Iron," Journal of the Iron and Steel Institute, v. 118, 1928 (2).
- ³ Pearce, "The Elasticity, Deflection, and Resilience of Cast Iron," Journal of the Iron and Steel Institute, v. 120, 1934 (1).
- ⁴ Donaldson, "The Thermal Conductivities of Grey Cast Irons," Proceedings of the Institution of Mechanical Engineers, 1928, No. 4. "Strength of Grey Cast Irons at Elevated Temperatures," Journal of the West of Scotland Iron and Steel Institute, v. 38, 1930-31. "Thermal Conductivity of Wrought Iron, Steel, Malleable Cast Iron, and Cast Iron," Journal of the Iron and Steel Institute, v. 128, 1933 (2).
- ⁵ Williams, "Cylinder Wear," The Engineer, v. 155, June 23 and 30, 1933.
- ⁶ Friend, "Corrosion of Iron and Steel," Longmans, 1911. "The Corrosion of Iron," Carnegie Scholarship Memoirs, 1922.
- ⁷ Perchke and Popova, "Choice of Alloys for Caustic Soda and Caustic Potash Plant," Chimie et Industrie, March, 1930.
- ⁸ Inglis, "Some Notes on Heat-Resisting Metals," Transactions of the Society of Glass Technology, v. 17, 1933.
- ⁹ Devine, Wilhelm, and Schmidt, "Comparative Resistance of Certain Commercial Ferrous Materials to Corrosion by Gaseous Hydrogen Sulphide," Technical Publication No. 531, American Institute of Mining and Metallurgical Engineers.