STEELS WITH IMPROVED PROPERTIES*

By Dr T. L. F. Muller, B.Sc.(Rhodes), M.Met.A.I.M.(Sheffield), Ph.D.(Sheffield) (Visitor)

INTRODUCTION

During the past decade a wealth of knowledge has been acquired about the mechanisms and reactions responsible for the physical properties of metals. In the field of steels, in particular, research of a fundamental nature has enabled us to interpret mechanical properties such as hardness, brittleness, creep strength, etc., in terms of atomic interactions. So rapid has been the development of physical metallurgy in some fields that publications are often outdated by the time they appear in print.

The development of new steel products has been rather empirical by nature in the past and only during the past few years have new products been "designed" in terms of known physico-metallurgical phenomena. However, although this is a great stride forward it should be added that the development of a commercially successful product is a far more complicated process. In addition to the physico-metallurgical background this requires consideration of factors such as low production cost, market research and probably most valuable of all, an interested end user to co-operate in the development.

This paper deals rather briefly with three of the most recent developments in steels in Britain with which the author has had some association. The main purpose of this is to demonstrate how the improved properties of the new product are based upon established physico-metallurgical phenomena. Generally speaking a commercially successful product of the type described here offers similar properties to that of an existing product at lower cost or has improved properties or features such as greater ease of cold forming, at similar cost.

ULTRA-FINE GRAIN STRUCTURAL STEELS

The development of higher yield strength structural steels dates back over a considerable number of years and has led to a variety of types. The one described below contains niobium as a grain refiner in an otherwise conventional mild steel matrix. By controlled rolling in a strip mill considerably increased yield strengths are obtained.

In Fig. 1 are shown somewhat diagrammatically the relative hardening effects of carbon and manganese on ferrite. It will be seen that strength is enhanced by the solid solution hardening effect of manganese and the pearlite content. An obvious limitation of high pearlite content is a lack of cold workability and weldability. Manganese has to be restricted to low levels for the same reasons. The two other mechanisms which are known to impart higher strength are precipitation hardening and grain refinement. Precipitation hardening is impractical in most cases for structural steels and it is therefore clear that only grain refinement remains as a potentially useful strengthening mechanism.

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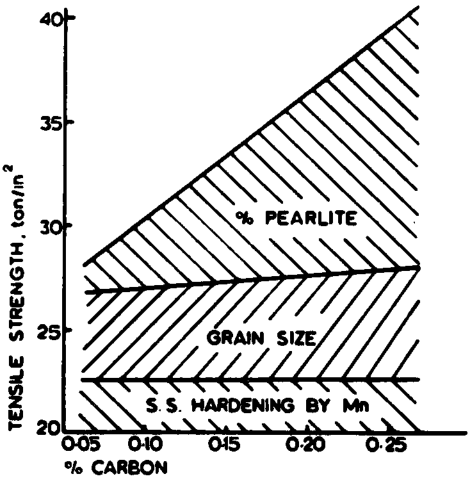

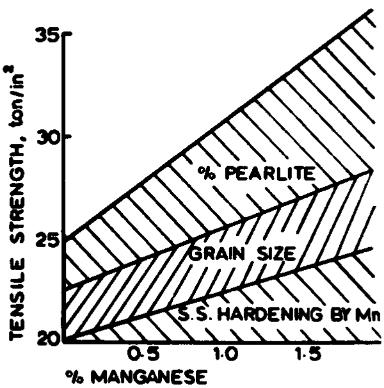

Fig. 1—Factors contributing to the strength of C-Mn steel

Grain size has no effect on weldability and can be beneficial for cold workability. Moreover a decrease in grain size results in a decrease in the impact transition temperature. The relationship between grain size and yield stress is commonly expressed as follows, as the Hall-Petch relationship:

$$\sigma_{ys} = \sigma_o + k_y d^{-\frac{1}{2}}$$

where σ_{ys} is the yield stress, σ_o and k_y are constants and d is the grain diameter.

Actual results achieved on this product (Fig. 2) show that a refinement of ferritic grain size from 9 ASTM to 12 ASTM results in an increase in yield strength of approximately 8 ton/in^2.

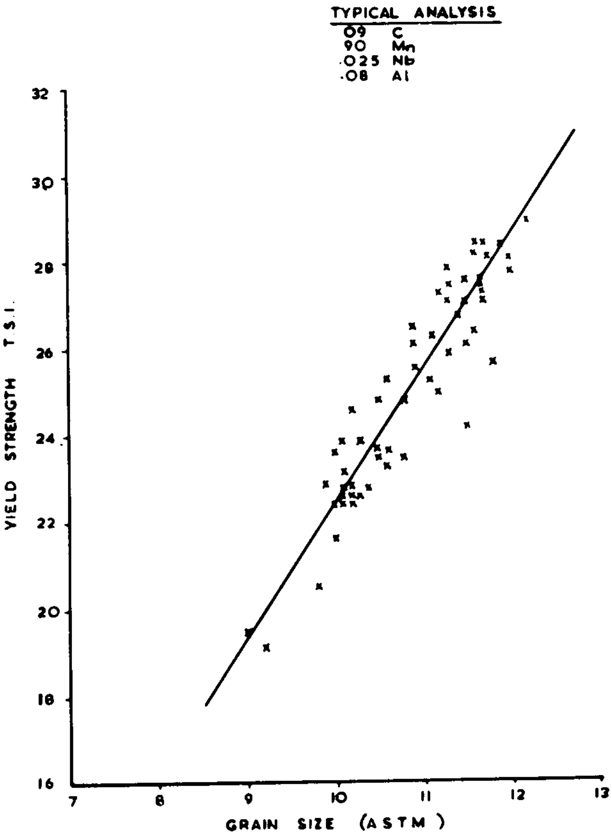

Fig. 2—Grain size V yield strength on hypress steels

Only 0·02 per cent niobium is required in this product for refinement of the ferritic grain size. An important part of the process is rolling to lower finishing temperatures than normal followed by water cooling to prevent grain growth before coiling. Fig. 3 shows that austenization at high temperatures before rolling, finish rolling at low temperatures and fast cooling are conducive to fine grain and high strength. The "laminar flow" cooling unit attached to the hot strip mill at Steel Peech and Tozer is shown in operation in Fig. 4.

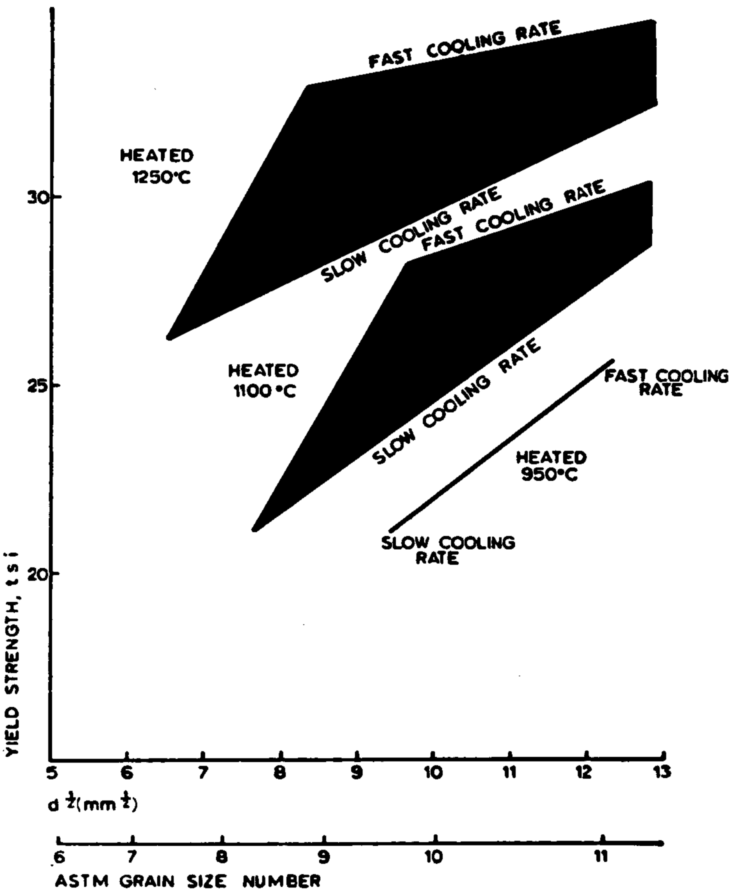

Fig. 3—The effect of rolling variables on the strength-grain size relationship of Nb stee

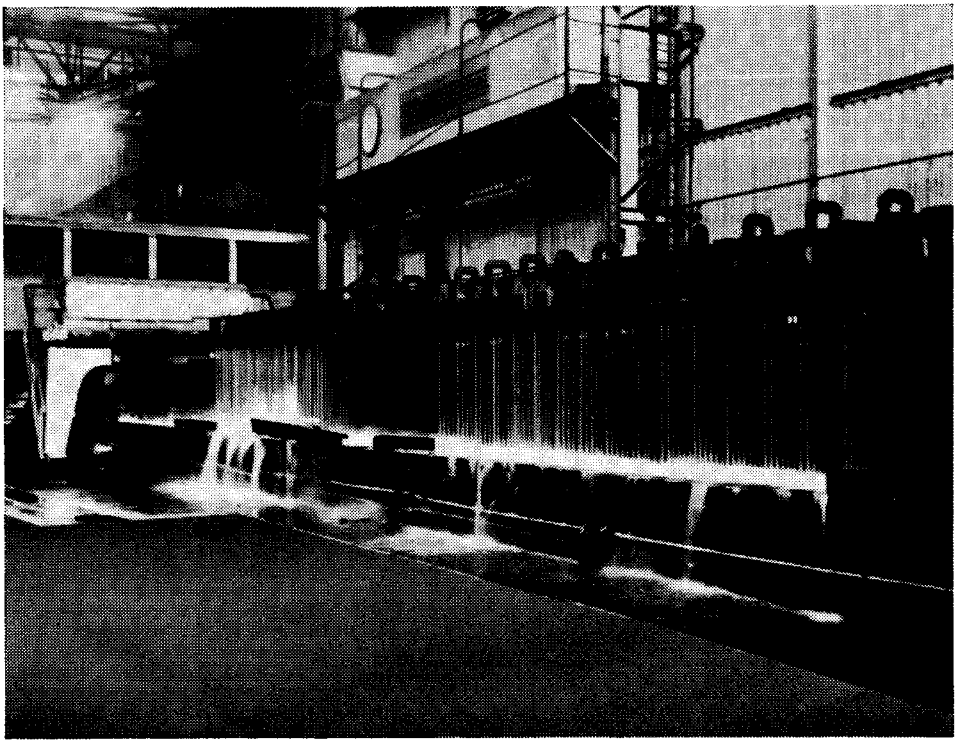

Fig. 4

The strip so produced can have a yield strength of 29 ton/in.^{2} in sections up to ¼ in. thick. A range of steels with slight differences in composition can be produced with a yield strength ranging from 20 to 29 ton/in.^{2}. Formability in these steels is excellent and weldability is equal to that of mild steels. Typical applications are chassis members for heavy duty trucks, wheel hubs and in containers (Fig. 5) which are increasingly being used for European goods traffic. A typical cross-member is shown in Fig. 6. The emphasis in this case is obviously on weight saving. An additional bonus is the improved impact transition temperature which is approximately 40°C lower than in mild steel. Moreover, in an application such as a wheel the increased fatigue resistance is of real value.

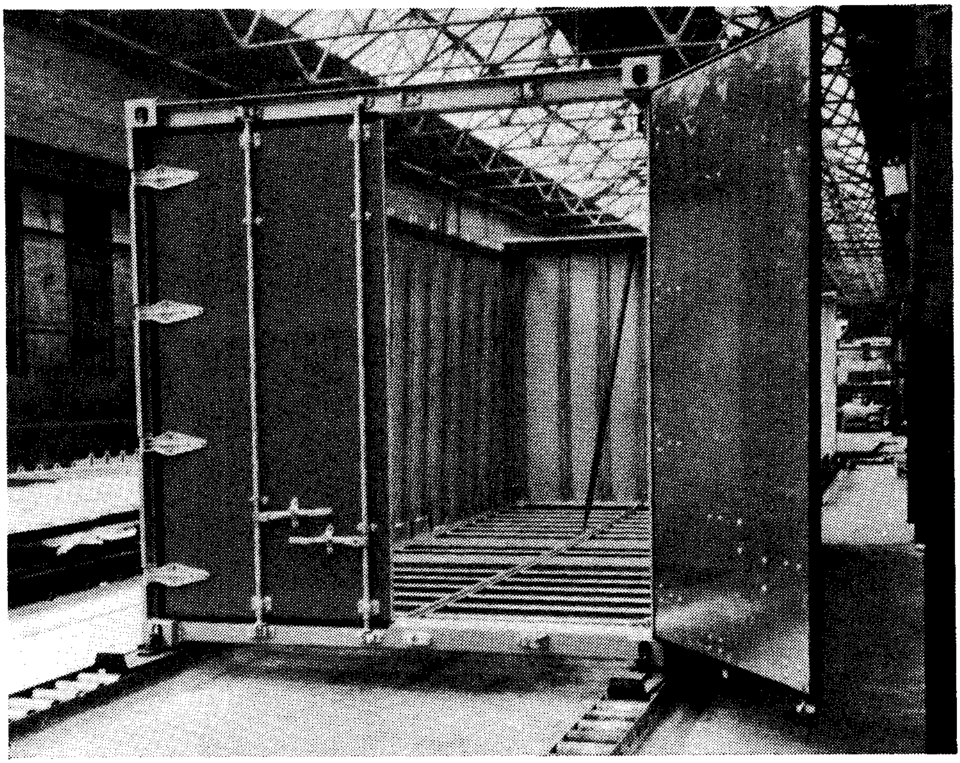

Fig. 5

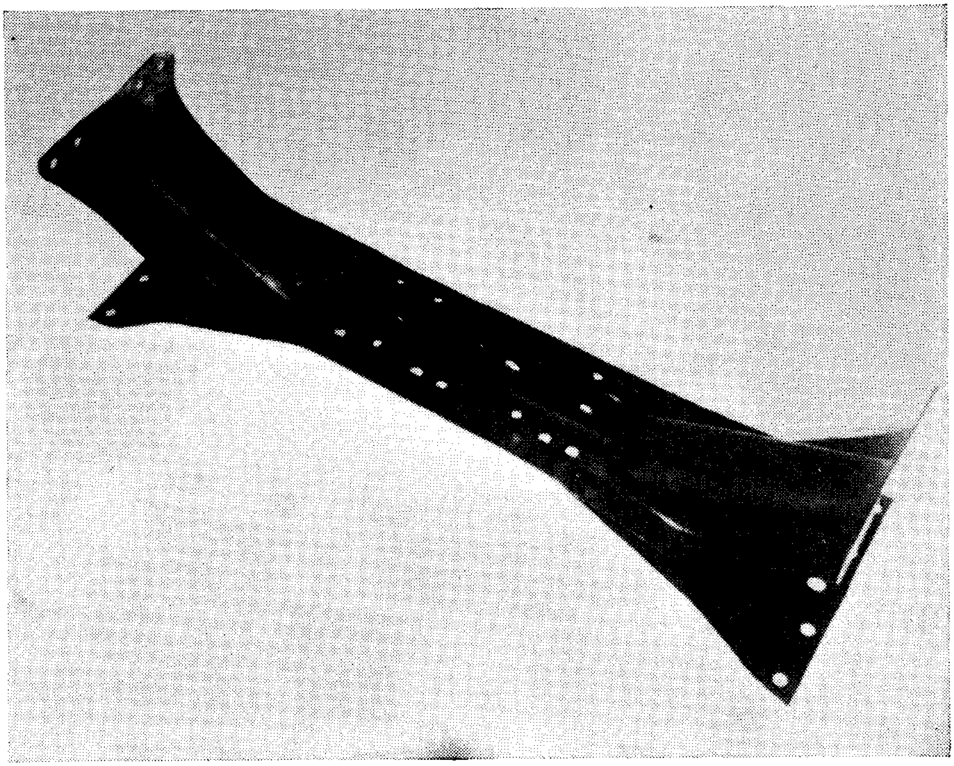

Fig. 6

A similar development for components of much thicker section also needs to be mentioned. This is the use of vanadium nitride in a mild steel composition as a grain refiner, the vanadium and nitrogen contents being approximately 0·15 and 0·015 per cent, respectively.

Such a ferrite-pearlite steel can be used in the as-welded or normalised conditions for products such as high pressure gas pipe-line flanges, with a yield strength of approximately 29 ton/in^2. Of greater importance in this case are the excellent low temperature impact properties. A typical flange made from this steel is shown in Fig. 7.

C-Mn BORON REPLACEMENT STEELS

An important commercial development of late has been the use of boron in carbon manganese steels containing controlled amounts of residual elements normally found in scrap as replacements for conventional low alloy steels.

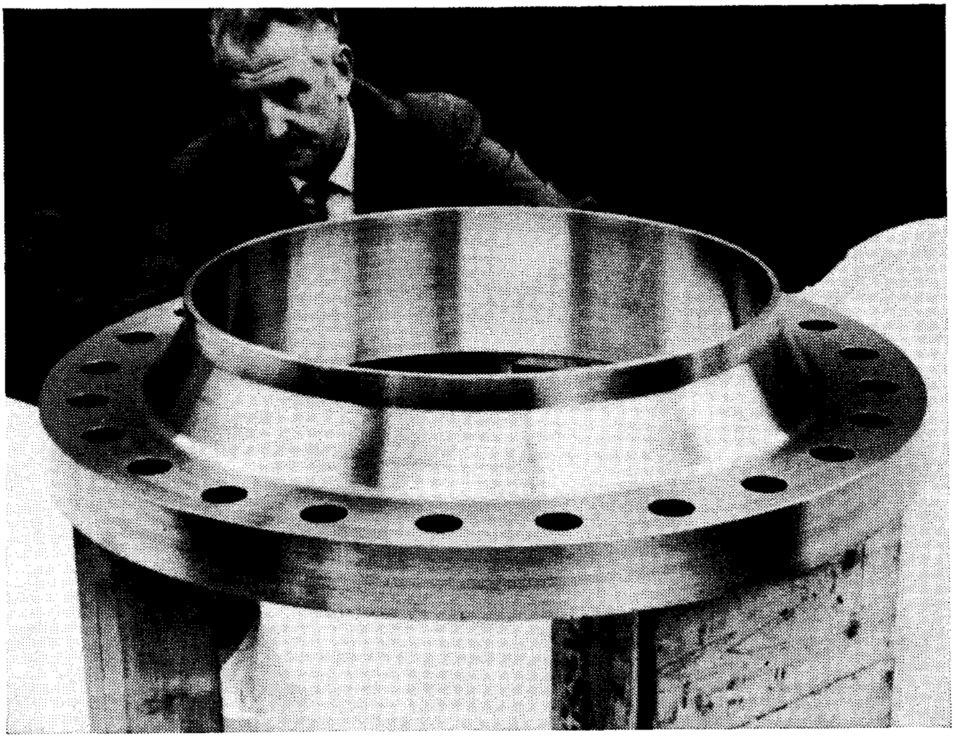

Fig. 7

It dawned on the electric steelmakers in Britain some years ago that the high residual amounts of nickel, chromium and molybdenum in present day commercial scrap could be effectively used. By utilizing automatic spectrometric equipment capable of rapid analysis and employing thorough scrap segregation, carbon manganese steels can be made with superior hardenability and strength properties. At Steel Peech & Tozer this development was extended in order to simulate the properties obtainable in low alloy steels by using boron as the main hardenability element in such carbon manganese steels. Two main types were developed[2], namely through-hardening grades and carburizing grades, each covering a range of hardenability and core strengths.

Boron is added in small amounts of the order of ·001 per cent and to prevent boron-fade due to combination with oxygen and nitrogen, de-oxidation and de-nitrogenization during steelmaking is very important. To ensure against boron-fade and to facilitate heat treatment by the customer these steels are supplied to a guaranteed Jominy hardenability band. In Fig. 8 are shown the Jominy curves of one of these steels and SAE 8620, which it was designed to replace.

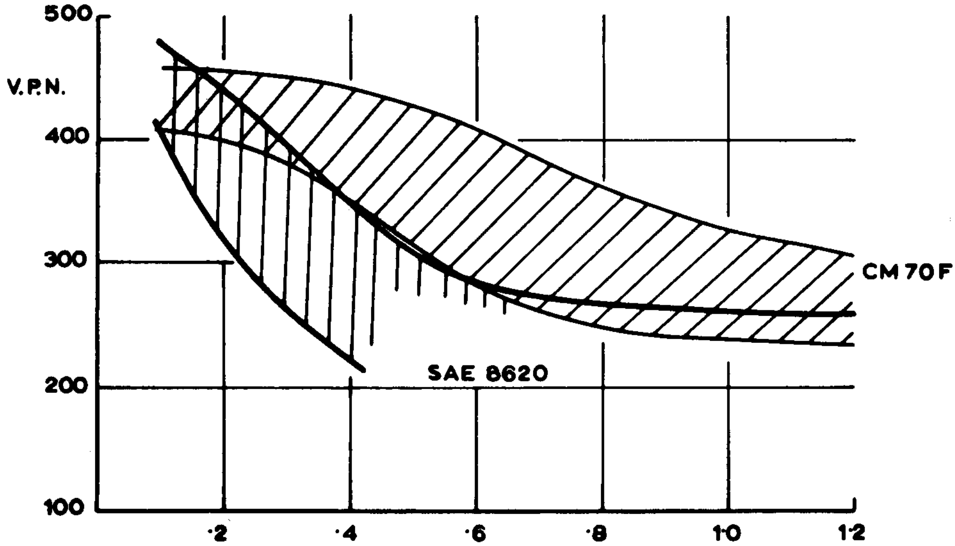

Fig. 8—A comparison of the standard jominy hardenability properties of Phoenix CM. 70F and SAE. 8620

In Table I is given a comparison of the properties obtainable in different section sizes of SAE 8622 and a replacement steel.

TABLE I

COMPARISON OF PROPERTIES: SAE.8622H AND CM.60

Typical applications: Gear box transmission shafts and gears

MECHANICAL PROPERTIES:

		$\frac{3}{4}$ in.	$1\frac{1}{8}$ in.
8622H	U.T.S. (t.s.i.)	65 - 85	55 - 75
	0·2 per cent P.S.	45 - 60	40 - 55
	IZOD (ft lbs)	30	30
CM.60	U.T.S. (t.s.i.)	60 - 75	55 - 65
	0·2 per cent P.S.	45 - 60	40 - 55
	IZOD (ft lbs)	30	30

HARDENABILITY:

	J_1	J_4	J_8	J_{16}
8622H	43/50	30/44	20/32	—/25
CM.60	40/45	27/43	18/32	—/25

TYPICAL ANALYSIS:

8622H	0·20 C	·75 Mn	·5 Ni	·5 Cr	·25 Mo
CM.60	·15 C	1·0 Mn	Boron treated		

The increasing use of the carburizing grades of replacement steels in the motor car industry has been very encouraging. At the time of writing these steels cost at least 10 per cent less than conventional low alloy steels and component tests have shown them to be quite as good as conventional steels.

Typical applications are shown in Figs. 9 and 10. The latter case is of particular interest since the component, a front wheel driveshaft, is cold forged. An important advantage of the boron steels is that they have low annealed hardness due to the fact that boron does not strengthen the ferrite matrix as do the alloying elements normally present in alloy steels. As a result extrusion pressures are lower and more severe cold deformation can be applied. It is clear that with an increasing interest in cold forming, boron steels of this type are going to become very widely used in the low alloy steel field in future.

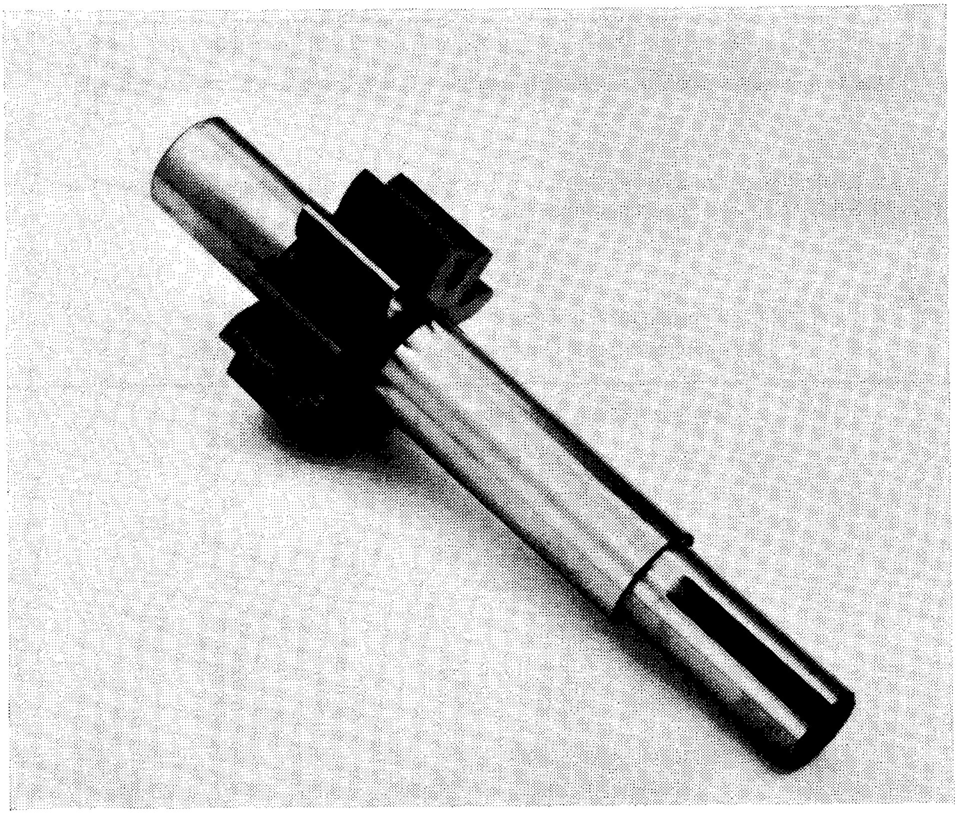

Fig. 9

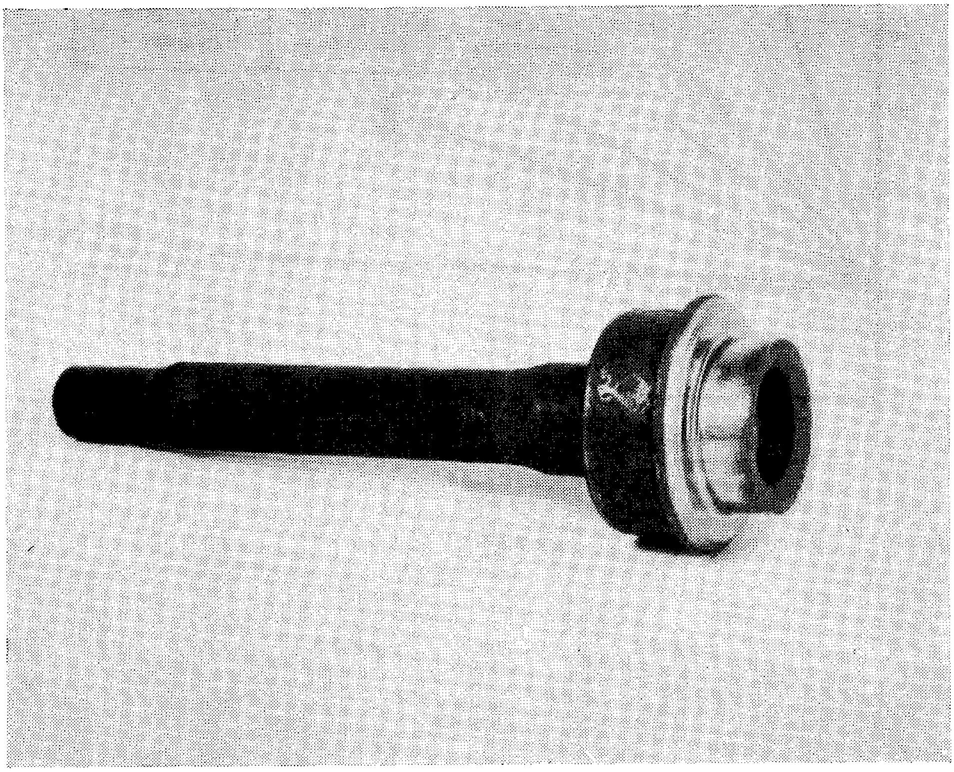

Fig. 10

HIGH NITROGEN STAINLESS STEELS

The third development which is of special interest involves increasing the strength of an austenitic stainless steel by solid solution hardening of the matrix[3].

Reference to Fig. 11 shows that the substitutional hardening elements such as manganese, cobalt, nickel, etc. impart very little strength to austenite. However, the interstitial elements carbon and nitrogen are seen to have a very pronounced strengthening effect. Since carbon has obvious limitations with respect to carbide precipitation, nitrogen remains as a powerful strengthener. Other possible methods of strengthening stainless steels are given below.

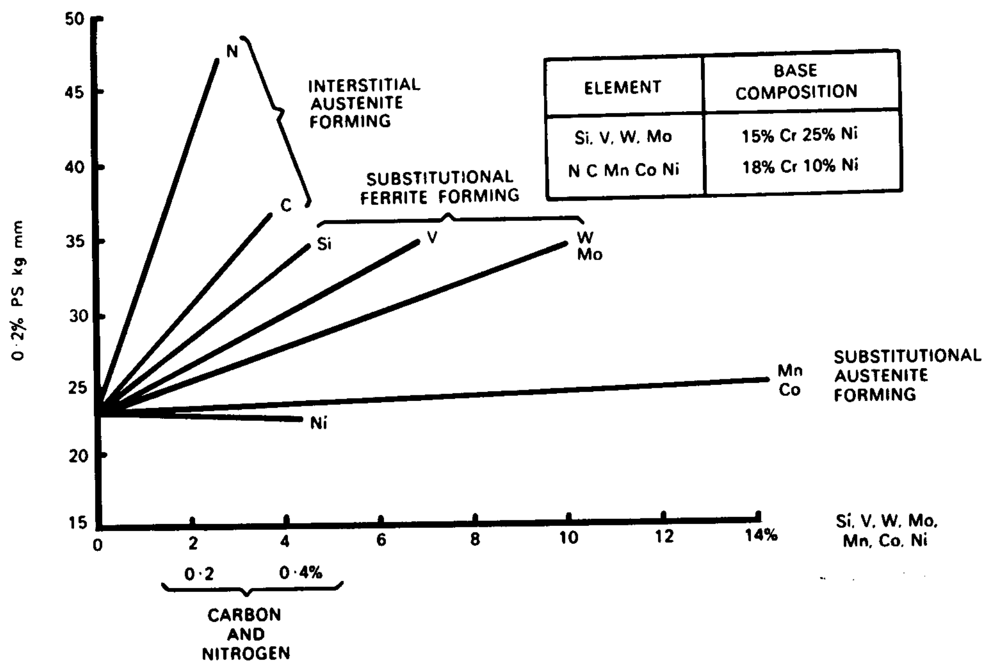

Fig. 11

An obvious method of increasing the strength of stainless steel is by cold working but there are severe limitations as regards shape and size of the product, e.g. this can be used successfully only on thin continuous products such as wire and sheet. Another method is precipitation hardening and steels containing inter-metallic precipitates which incorporate aluminium, titanium, etc., are available. However, these steels are generally unsuitable for welding due to reactions in the heat affected zone which give rise to embrittlement and decreased corrosion resistance.

A further method of strengthening austenite is by warm working, i.e. by rolling or forging at temperatures considerably below normal hot working temperatures. The substructure so produced strengthens in a similar way to a refinement of the normal grain size. In Fig. 12 is shown the effect of finish rolling temperature on the yield strengths of some austenitic steels. The increase in strength when finishing at temperatures below approximately 950°C is very large indeed. Very interesting also is the fact that the impact properties are not adversely affected. The combination of solid solution hardening with 0·2 per cent nitrogen and warm working can be seen to produce greatly improved properties.

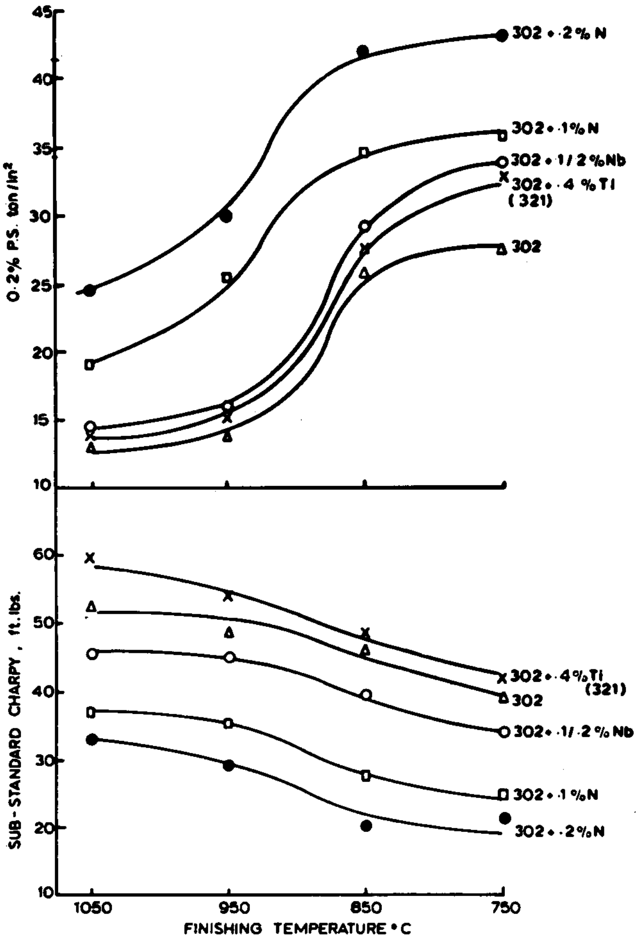

Fig. 12—The effect of finishing temperature and composition on the properties of austenitic stainless steels

The enhanced strength properties of a 0·2 per cent N_2 austenitic steel which has been developed by Messrs. S. Fox and Company Limited, are shown in Fig. 13. It will be seen that the 0·2 per cent proof stress is raised by approximately 40 per cent at temperatures up to 400°C. Pressure vessel burst tests conducted by Messrs Samuel Fox have shown that a 25 per cent weight saving can be effected by using these high strength stainless steels instead of the normal types without any loss in ductility or the use of special welding techniques. The corrosion resistance has not been found to be affected adversely.

The greatly enhanced mechanical properites of this product so far outweigh the increased cost that this has proved to be a very successful commercial development.

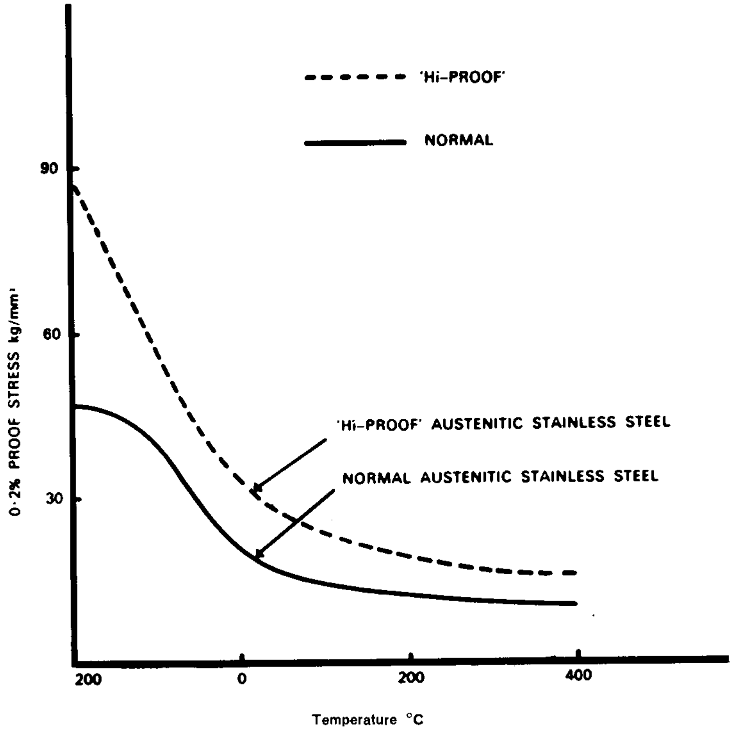

Fig. 13—Typical 0·2% proof stress curves

The rather brief description of each of the three developments makes no mention of the technical frustrations accompanying development work of this nature nor of the uncertainty of the commercial viability of the new product.

However, it serves to show how our present day knowledge of physico-metallurgical phenomena can be employed to design an improved or cheaper product.

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