Contributions to discussion

A. H. Mokken: I am pleased to have been given this opportunity to make a contribution to Dr Muller's paper tonight. The reason for this is that, at one stage in our careers, we were associates in the same undertaking. Dr Muller, then fresh from University, with a degree in pure science, had just stepped onto the first rung of the ladder, which, it was then thought, would lead him to a career in gold extractive metallurgy. However, endowed with an enquiring mind and conscious of a lack of fundamental training in general metallurgy and engineering, he felt a need for further academic study. To meet this need and, more importantly, to meet the necessary finances, he found his opportunity in steel. Armed with a bursary, he bade farewell to gold and proceeded overseas, to the University of Sheffield, to train as a steel metallurgist. The outcome of these academic efforts, which were followed by assignments in the steel industry and a further period at Sheffield, is the man we have listened to tonight—a highly qualified metallurgist who has displayed a sound knowledge of his subject.

In choosing Sheffield, Dr Muller became associated with a steelmaking centre of world renown, a centre usually credited with the first systematic production of alloy steels, as far back as the 18th century. Since that time, great advances have been made in the production of alloy steels and this is especially so in the last decade or two, when major developments in civil, mechanical, electrical, aeronautical and nuclear engineering have been made possible by the development of steels with improved properties. In spite of spectacular advances in the technology of non-ferrous alloys, plastics and other materials of construction, steel has maintained its role as a pre-eminent material for engineering use. With the gradual accumulation of data on the properties of steels, and the use of thin film electron microscopy, to study the behaviour and characteristics of such phenomena as dislocations in metals and other microstructural features, the physical metallurgist appears to be approaching the stage of an exact understanding of such phenomena as strength, ductility and brittleness—a knowledge which could lead to close control of such properties and, therefore, to the attainment of the highest goals.

An interesting example, illustrating the use of fundamental principles, based on physico-metallurgical research, is the development of the maraging steels developed by Bieber at the International Nickel Company. These steels have met the extreme technological requirements of the space age by providing the material for the cases of large rockets in which qualities, such as high tensile strength, toughness, workability and weldability are most important.

Attractive as they might appear to be in considerations of savings of weight, cost of erection, transport of materials and foundations, the use of high strength steels has been accompanied by special problems such as brittle fracture, hydrogen embrittlement, notch-toughness and fatigue. It has been found that high strength steels, which performed acceptably in conventional tension tests, were found to undergo failure, in a brittle manner, in service. Hydrogen embrittlement has caused spectacular failures at a fraction of the normal ultimate tensile strength, and a lack of correlation between fatigue and tensile strengths has diminished the advantages to be obtained from the use of high strength steel in some applications. A new approach to the selection of materials for engineering design has resulted from a consideration of these phenomena in which strength, as such, is no longer as significant as it was previously.

Parallel with the development of high strength steel has been the need for suitable techniques for joining component parts and here welding has played an important role. Again a thorough understanding of the principles involved, coupled with advanced workmanship, are essential if the properties of the parent metal are to be retained to the highest degree. In this connection I believe that a course in practical welding metallurgy is being contemplated, locally, to meet this need.

Of particular interest to the mining industry, especially in corrosive environments, are the high strength stainless steels for which a number of applications are visualized —one of which would be high pressure and even low pressure pipe columns and other pressure vessels. In the design of uranium plants, especially, the use of these high strength steels should receive serious consideration.

In addition to the properties of corrosion resistance and strength, a further requirement of stainless steel, which, if perfected, would find wide application in the mining industry, is that of resistance to wear and abrasion. Efforts are already being directed towards this end and it is possible that, by application of the fundamental physico-metallurgical approach, a product could be produced that will surpass all expectations.

The rapid industrial progress experienced in this country, over the past few decades, has placed heavy demands on the supply of steel of various qualities. The gradual replacement of imported intermediate products and components in the motor, machinery and metal fabricating industries by local manufacture, will place increasing demands on local productive capacity. This, in turn, will stimulate the production in this country of steels, hitherto imported, and permit of wider utilization of these superior products by industry, in general.

In conclusion, I would like to thank Dr Muller for preparing his paper and presenting it to us, in person. Speaking for the gold mining industry, it is good to know that, in Dr Muller we have a person who is no stranger to us, a person who is actively associated with the development and production of high quality steel, and soneone who, I am sure, will always be prepared to give us his best advice should we venture into the field of steels with improved properties.

Professor G. T. van Rooyen: I have listened to the paper by Dr Muller with great interest. Due to unavoidable circumstances, I have not had the opportunity to read Dr Muller's paper beforehand, but I am sure that I express an unanimous opinion when I commend Dr Muller on a really excellent and well prepared paper. The subject matter he has chosen for his paper is of great interest and importance to all engineers who use steel. The advantages of some of the new steels are quite spectacular, especially when large steel structures such as long span bridges are considered. In such cases the stresses in the structure are to a large extent determined by the weight of the structure. Using a higher strength steel in such a case enables the designer to increase the working stresses, which consequently reduces the weight of the structure which in turn results in a lower stress enabling the section size to be further reduced. This ultimately results in much greater percentage saving of weight than the initial percentage increase in the operating stress. In many cases the increase in the strength of the steel is also accompanied with a greater resistance to atmospheric corrosion, eliminating the necessity of painting the structure, and further emphasizing the advantage of this type of steel.

South African engineers have up to the present been slow in taking advantage of these improved properties. One of the many reasons for this is undoubtedly the slight increase in cost and the reluctance to change their designs to take full advantage of the higher strength. The increased cost of these low carbon low alloy constructional steels, however, is out of proportion in relation to the cost of the additional alloying elements used. Most of the extra price seems to be associated with the fact that it is regarded as a special type of steel. More widespread use in the future must result in a smaller price differential between it and the conventional low carbon steels.

The title of Dr Muller's paper 'Steels with improved properties' is indeed well chosen. A point worth emphasizing this evening is that improved properties should not only be regarded as steel with superior strength properties, but that due regard should also be given to other properties which might be improved such as ductility and fracture toughness. As a matter of fact if strength were the only consideration, the strength of mild steel could be sizeably increased by the simple addition of carbon to increase the carbon content or in some instances by cold working of the steel. The use of either cold worked steel or steels of a higher carbon content for structural purposes however, is complicated by lack of ductility, a high brittle transition temperature, a low fracture toughness and the special precautions which have to be taking during welding.

The development of a high strength structural steel indeed presents the metallurgical engineer with a real challenge. Quite apart from the need of combining high strength with high ductility, complicated heat treatments to develop these properties are almost out of the question in large tonnage production. Ideally the improved properties must be attained in the as rolled condition. Similarly the alloying elements used must be readily available and amenable to conventional steelmaking practice so that the price of the final product remains competitive.

Of all the known methods of obtaining increased strength, the reduction of the grain size is one of the most successful means of obtaining the increased strength coupled with a high fracture toughness and a low brittle transition temperature. In this respect the low carbon, low alloy steels with alloying additions of niobium and vanadium to which Dr Muller has referred have proved to be particularly successful.

During the past decades great progress has been made in the application of dislocation theory to evaluate the factors which determine the strength properties of metals and alloys. Thus we know, for example, in the case of solid solution hardening, that the strength increase due to a solute is, to a large extent, dependant on the restraining effect which local lattice strains, due to differences in atomic size, and or the effect which local changes in elastic modulus has on the movement of dislocations through the lattice. Thus, for example, phosphorous in solid solution in steel with the exception of carbon and nitrogen is one of the most effective hardeners, yielding an increase of 10,000 p.s.i. in the yield stress for every 0·1 per cent phosphorus added compared with only 300 p.s.i. for every 0·1 per cent vanadium present in solid solution. The adverse effect of phosphorus on the ductility however is so striking that it is generally considered as an underisable element. Most steel specifications consequently limits the maximum percentage phosphorus to less than 0·05 per cent. It is in this respect that the application of dislocation theory or, for that matter, any theory has been least successful in predicting the factors which determine the ductility of an alloy. From this point of view alloy development is still largely a matter of trial and error. This stresses the need not only for more applied research but also for an intensified basic research programme to ascertain the basic factors which determines the fracture toughness and the ductility of alloys.

A long sought ideal in alloy development has always been to turn alloying elements such as phosphorus which are generally considered harmful into useful elements. If this, for example, is possible in the case of phosphorus, not only will improved properties be obtained but the steel manufacturing process simplified resulting in a lowering of the cost. Quite a number of commercial steels, mostly low carbon low alloy steels for structural purposes, are known which contain deliberate small additions of phosphorus together with additions of manganese, copper, chromium and silicon.

Various authorities maintain that the small additions of phosphorus not only increases the strength with a minimal influence on the ductility but that it also aids in rendering the steel more resistant to atmospheric corrosion.

Research[1] has shown that the embrittling effect of phosphorus in pure ferrite without carbon is much greater than when small amounts of carbon are present. The embrittling effect of phosphorus is usually associated with phosphorus segregation at grain boundaries. This segregation is most probably in the form of a mono-atomic layer[2], at the grain boundary and which results in a lowering of the grain boundary energy. This embrittling effect is much more pronounced after an isothermal treatment in the temperature range 600-900°C followed by quenching. When carbon is added it has been suggested that the formation of a grain boundary film of cementite competes with phosphorus segregation and that carbon by this means limits the deleterious effect of phosphorus by limiting the grain boundary segregation. In order to be effective such Fe-C-P alloys should be cooled slowly. I was particularly interested in Dr Muller's reference to the use of nitrogen as an alloying element in austenitic stainless steel. It occurred to me that a combination of nitrogen as well as phosphorus ought to be investigated. Nitrogen for example has a much higher solubility than carbon in ferrite. Hence the possibility exists that nitrogen may be even more successful than carbon in eliminating the adverse effect of phosphorus in low alloy steels.

REFERENCES

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2. Hondros, E. D. *Proc. Roy. Soc.* 1965, **286** No. 1407.

D. P. Rowlands: High yield strength steels are in regular use in the Republic, a typical example of their application being the S.A.R. trailer shown in Fig. 1 where the use of a 67,000 p.s.i. yield strength steel has allowed a substantial increase in payload.

There are two main types, the first being a quenched and tempered 100,000 p.s.i. yield strength; the second being a steel similar to that as discussed by Dr Muller, which exhibits a 67,000 p.s.i. yield strength in the 'as rolled' condition.

This latter steel, not suffering from the problem of distortion during heat treatment, has ably fulfilled the gap which existed in the requirement for structural sections of a wide range of sizes with strengths superior to those as exhibited by conventional BS.15 and even BS.968.

It may be of further interest to know that a steel of this type has now been included in the recently issued British Standards Institution Specification for weldable structural steels, BS.4360 : 1968.

Table 6 and Table 7 from this specification are given in Fig. 2 and Fig. 3, showing respectively the chemical composition and mechanical properties of plates for all steels included in this specification. As may be seen this specification now covers, among others, the familiar BS.15 and BS.968; Grade 55c being relevant to tonight's discussion. The specification also covers the requirements for flat, round and square bars.

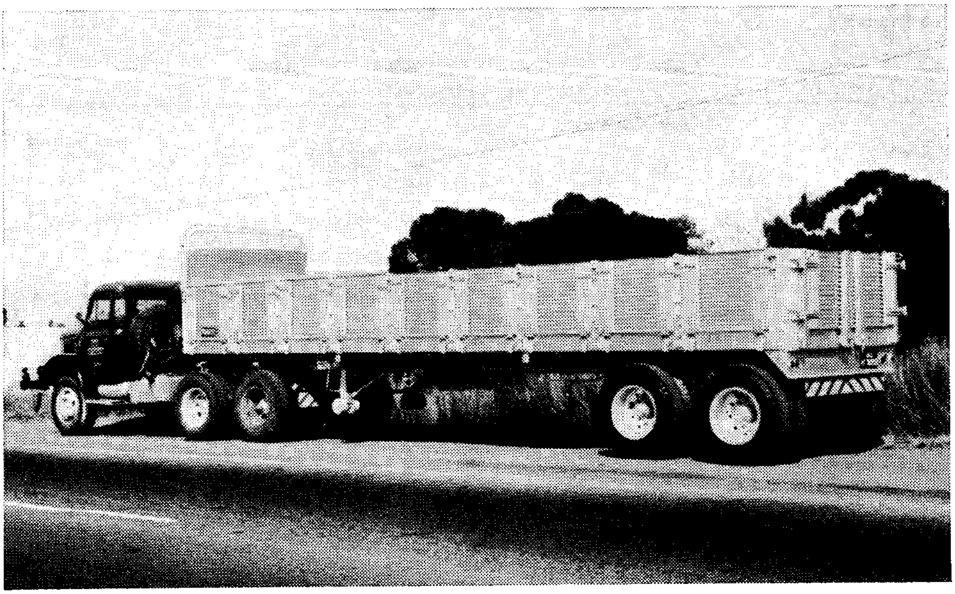

Fig. 1—An illustration of an S.A.R. trailer built to the design of the Fruehauf Corporation of America. Use is made of a 67,000 p.s.i. yield strength steel in the main load bearing beams, which are of a fabricated I beam construction; a substantial saving of weight being effected

The high yield point of this steel is developed by controlled rolling, particularly in the control of the finishing rolling temperatures. Thus the yield point is raised without materially altering the ultimate tensile strength, but this added strength may be maintained due to the niobium exerting its grain controlling effect and thus rendering it unnecessary to normalize.

The main use of this steel has been as structural sections, and to a lesser extent in plate form. Round and square bar is seldom used, because the size of cross section limits the effect by which the yield strength is raised due to the rolling technique, thus bars of large cross section show little advantage in strength.

One of the factors which is raised in opposition to the use of steels of this nature is that the deflection for a given load is not altered, due to Young's Modulus being virtually constant for all steels. However, this has been overcome by the use of fabricated sections. A typical example is the fabricated I beam. A web of mild steel is used, of such a depth as may be desired to overcome the deflection problem. The flanges are of this high yield strength steel, which may be used in much lighter sections than that required for mild steel, having the greatly improved strength, and fatigue resistance.

This steel finds its greatest application where weight saving is of major concern; for example, in trailers and crane booms, thus allowing greater payload for the same gross weight, and greater lifting capacity for the same power utilization. Numerous heavy duty trailers have been built using this steel, and with imaginative design, quite phenomenal weight savings have been effected by different manufacturers. Mobile crane booms of 150 ft in length have also been manufactured.

BS 4360 : 1968

TABLE 6. CHEMICAL COMPOSITION FOR PLATES

Figures in parentheses make reference to the notes

Grade		Chemical composition, %						Normal deoxidation condition	Supply[7] condition	Nearest equivalent previous specification
		C max.	Si	Mn max.	Nb[4] max.	S max.	P max.			
40A[1]	Ladle	0·22	—	—	—	0·050	0·050	Semi-killed	As rolled	BS 3706
	Product[2]	0·27	—	—	—	0·060	0·060			
40B[1]	Ladle	0·20	—	1·5	—	0·050	0·050	Semi-killed	As rolled	—
	Product	0·25	—	1·6	—	0·060	0·060			
40C[5]	Ladle	0·18	—	1·5	—	0·050	0·050	Semi-killed	As rolled	BS 2762—NDIA
	Product	0·22	—	1·6	—	0·060	0·060			
40D[5]	Ladle	0·16	—	1·5	0·10	0·050	0·050	Semi-killed	Normalized	—
	Product	0·19	—	1·6	—	0·060	0·060	+ Nb		
40E[5]	Ladle	0·16	0·10/0·50	1·5	—	0·040	0·040	Si-killed +	Normalized	BS 2762—NDIVA
	Product	0·19	0·10/0·55	1·6	—	0·050	0·050	fine grain		
43A1[1]	Ladle	0·25	—	—	—	0·050	0·050	Semi-killed	As rolled	BS 3706
	Product[2]	0·30	—	—	—	0·060	0·060			
43A[1]	Ladle	0·25	—	—	—	0·050	0·050	Semi-killed	As rolled	BS 15
	Product[2]	0·30	—	—	—	0·060	0·060			
43B[1]	Ladle	0·22	—	1·5	—	0·050	0·050	Semi-killed	As rolled	—
	Product	0·26	—	1·6	—	0·060	0·060			
43C[5]	Ladle	0·18	—	1·5	—	0·050	0·050	Semi-killed	As rolled	BS 2762—NDIB
	Product	0·22	—	1·6	—	0·060	0·060			
43D[5]	Ladle	0·16	—	1·5	0·10	0·040	0·040	Semi-killed	Normalized	—
	Product	0·19	—	1·6	—	0·050	0·050	+ Nb		
43E[5]	Ladle	0·16	0·10/0·50	1·5	—	0·040	0·040	Si-killed +	Normalized	BS 2762—NDIVB
	Product	0·19	0·10/0·55	1·6	—	0·050	0·050	fine grain		
50A[1]	Ladle	0·23	—	1·6	—	0·050	0·050	Semi-killed	As rolled	—
	Product	0·27	—	1·7	—	0·060	0·060			
50B[1]	Ladle	0·20[3]	—/0·50	1·5	0·10	0·050	0·050	Semi-killed	Under ½ in,	BS 968 without
	Product	0·24	—/0·55	1·6	—	0·060	0·060	+ Nb	as rolled ½ in and over, normalized	impact tests
50C[1,5]	Ladle	0·20[3]	—/0·50	1·5	0·10	0·050	0·050	Semi-killed	Under ½ in,	BS 968 with impact
	Product	0·24	—/0·55	1·6	—	0·060	0·060	+ Nb	as rolled ½ in and over, normalized	tests
50D[5]	Ladle	0·18	0·10/0·50	1·5	0·10	0·040	0·040	Si-killed	Normalized	—
	Product	0·22	0·10/0·55	1·6	—	0·050	0·050	+ Nb		
55C[1,5]	Ladle	0·22	—/0·60	1·6[6]	0·10	0·040	0·040	Si-killed +	As rolled	—
	Product	0·26	—/0·65	1·7	—	0·050	0·050	Nb + fine grain		
55E[1,5]	Ladle	0·22	—/0·60	1·6[6]	0·10	0·040	0·040	Si-killed +	Normalized	—
	Product	0·26	—/0·65	1·7	—	0·050	0·050	Nb + fine grain		

Fig. 2—Table 6 of BS. 4360, giving the chemical composition of the different grades; grade 55cc being relevant to this discussion

NOTES

1. These grades may also be supplied containing either 0·20/0·35% or 0·35/0·50% Copper, if specified on the order.
2. For rimming steels, the limits for product analysis shall be 1·25 times the specified ladle analysis (see 4·1)
3. For material over ⅝ in. (16 mm) thick a maximum carbon content of 0·22% for ladle analysis, and 0·26% for product analysis is permitted
4. Where Niobium is indicated, other grain refining elements may be used, each up to the maximum percentage indicated. If micro-elements other than Niobium are to be used the manufacturer shall inform the purchaser at the time of the enquiry or order.
5. By agreement can be supplied to a maximum carbon equivalent value (see 6·3)
6. Including Chromium, if used as an alloying element
7. Plates can be supplied in other conditions by agreement (see Clause 5)

BS 4360 : 1968

TABLE 7. MECHANICAL PROPERTIES FOR PLATES

Figures in parentheses make reference to notes

Grade	Tensile strength	Yield stress, min. Up to and including ⅝ in	Yield stress, min. Over ⅝ in up to and including 1 ½ in	Yield stress, min. Over 1 ½ in up to and including 2 ½ in	Yield stress, min. Over 2 ½ in up to and including 4 in(2)	Elongation, min. on gauge length of 8 in	Elongation, min. on gauge length of $5{\cdot}65\sqrt{S_o}$	Maximum bend radius	Charpy V-notch impact test Temp.	Charpy V-notch impact test Energy, minimum average	Charpy V-notch impact test Thickness max.	Nearest equivalent previous specification
	tonf/in²	tonf/in²	tonf/in²	tonf/in²	tonf/in²	%	%		°C	ft lbf	in	
40A	26/31	—(3)	—	—	—	22(6)	25	1¼T(7)	—	—	—	BS 3706
40B	26/31	15·0	14·5	14·25	13·5	22(6)	25	1¼T(7)	R.T.(9)	20	2	—
40C	26/31	15·0	14·5(4)	14·25	13·5	22(6)	25	1¼T	0	20	2	BS 2762—NDIA
40D	26/31	17·0	16·0	15·5	14·5	22(6)	25	1¼T	− 10 − 20	30 20	3	—
40E	26/31	17·0	16·0	15·5	14·5	22(6)	25	1¼T	− 20 − 30 − 50	45 35 20	3	BS 2762—NDIVA
43A1	28/33	—(3)	—	—	—	20(6)	22	1½T	—	—	—	BS 3706
43A	28/33	16·0	15·5(5)	15·0	14·0	20(6)	22	1½T	—	—	—	BS 15
43B	28/33	16·0	15·5(5)	15·0	14·0	20(6)	22	1½T	R.T.(9)	20	2	—
43C	28/33	16·0	15·5(5)	15·25	14·5	20(6)	22	1½T	0	20	2	BS 2762—NDIB
43D	28/33	18·0	17·5	16·5	15·5	20(6)	22	1½T	− 10 − 20	30 20	3	—
43E	28/33	18·0	17·5	16·5	15·5	20(6)	22	1½T	− 20 − 30 − 50	45 35 20	3	BS 2762—NDIVB
50A	32/40	—	—	—	—	18(6)	20	1½T	—	—	—	—
50B	32/40(1)	23·0	22·5	22·0	21·0	18(6)	20	1T(7)	—	—	—	BS 968 without impact tests
50C	32/40(1)	23·0	22·5	22·0	21·0	18(6)	20	1T(8)	− 5 − 15	30 20	3	BS 968 with impact tests
50D	32/40	23·0	22·5	22·0	By agreement	18(6)	20	1½T	− 20 − 30	30 20	3	—
		Up to and including ⅝ in	**Over ⅝ in up to and including 1 in**	**Over 1 in up to and including 1 ½ in**	**Over 1 ½ in up to and including 2 ½ in**							
55C	36/45	29·0	28·0	27·0	—	17(6)	19	2T	0	20	¾(10)	—
55E	36/45	29·0	28·0	27·0	26·0	17(6)	19	1½T	− 20 − 30 − 50	45 35 20	2½	—

Fig. 3—Table 7 of BS. 4360, giving the mechanical properties of the different grades; grade 55 being relevant to this discussion

NOTES

1. Minimum tensile strength 31 tonf/in.² for material over 2½ in. thick
2. Minimum yield stress values for material over 4 in. thick to be agreed between the manufacturer and the purchaser.
3. Only bend tests required for material under ¼ in. thick.
4. Minimum yield stress 15·0 tonf/in.² for material up to and including ¾ in. thick.
5. Minimum yield stress 16·0 tonf/in.² for material up to and including ¾ in. thick.
6. Under ⅜ in. thick, 16% for Grades 40 and 43 and 15% for Grades 50 and 55
7. 1*T* for plates required for cold flanging
8. 1 ½*T* for material over 1 in. thick.
9. Only if specified on the order.
10. Also applicable to material over ¾ in. up to and including 1½ in. by agreement between the manufacturer and the purchaser.

Fabrication of this steel has presented no difficulties, and examination of trailers after extensive severe usage has revealed no short-comings, reports from all fields of operations having been extremely satisfying, indicating greater potential use for a steel of this type.

In conclusion, may I take this opportunity of thanking Dr Muller for a most interesting paper.

Dr Bereza: I wish to congratulate the author on his excellent paper. He discussed in it, some very important and topical problems confronting modern ferrous metallurgy.

Referring to high yield strength steels, I understand that vanadium is more potent than niobium in increasing the ultimate tensile and yield stresses in as rolled steel. This is probably due to the greater grain refinement obtained with vanadium as compared to that obtained with niobium additions. Moreover, vanadium steels apparently give more uniform properties than the niobium steels.

And now, I would like to highlight the role of vanadium as a substitute for aluminium in deoxidation of steel.

Aluminium, which is commonly used as a deoxidizer, has some disadvantages:

(i) Being a powerful deoxidizer, it reduces the oxygen content to very low levels at which type II sulphides tend to form. These sulphides, precipitating at the grain boundaries, are harmful in that they reduce ductility. The use of vanadium which is a relatively weak deoxidizer (midway between chromium and manganese), helps to avoid the trouble.

(ii) Aluminium can form hard angular oxide inclusions which further reduce ductility and, in particular, fatigue properties.

(iii) Moreover, there is a tendency for the oxides and sulphides produced by aluminium deoxidation to segregate to the surface of ingots which gives rise to stresses between the surface and centre of the ingot leading to cracks particularly in medium C-Cr steels.

On the other hand, because the melting point of vanadium oxides is low, they are more uniformly distributed and therefore, less harmful.

The uniform distribution of the oxides, nitrides and sulphides is further promoted by the fastest possible rate of solidification. This condition is satisfied by the continuous casting process which helps to produce a high quality steel.

It was stated that the main contribution towards strength arises from the ultra-fine grain size attributable to niobium carbide and vanadium nitride precipitation respectively.—Now, it is known that the carbide forming tendency of vanadium is less than that of niobium, or titanium for that matter. Nevertheless, the affinity of vanadium for carbon is very strong indeed and, therefore, in the absence of niobium and titanium, vanadium would be expected to combine with the nitrogen and carbon present in steel.

The Hall-Petch diagram does show dramatically the effect of the grain size on the yield point. According to this diagram a decrease in grain diameter by one unit, (which is roughly equivalent to 1½ A.S.T.M. units) increases the yield point by 4 tons per sq in.

Referring to boron steels, I wish to emphasize that while boron has no effect on the strength of hot rolled steel, it considerably improves hardenability. The effect of boron is extraordinary indeed, since as little as 0·001 per cent has a powerful effect on hardenability.

D. K. Maxwell: Dr Muller has discussed significant developments in the production of steels—developments which will be refined and possibly become a part of modern 'standard practice' (if this terms is not already an anachronism).

A most important effect of this type of development—particularly in a country such as ours, unfettered by heavy commitment to obsolete plant and equipment—is the opportunity offered to newly developing industries. These are the trends and patterns we should watch closely, investigate and adapt. We should learn to play the game of technological leapfrog, the game played with such spectacular results by Japan and Western Germany after the second world war.

Certainly a lot of our recent development has been spectacular and the eruption of a steel and alloy industry in the Eastern Transvaal over the last five years has dispensed with traditional precedents. However, unless we exploit the advantages of the late starter into new industries, our growth will be inhibited. We should be prepared to buy the latest and best in modern equipment, to aim at the latest and best in modern technology and when necessary, to buy the best men available from overseas.

The adoption of the L-D steel converter by the Japanese Steel Industry is an example of the stream-lined efficiency which can be characteristic of the establishment of (in this case) complete remodelling of an industry. Although the advantages of the L-D process are proven, neither Europe nor the U.S.A. could undertake a major conversion due to commitment to conventional plant.

On the question of the effect of substitution elements in steels, I would like to mention one or two interesting investigations at Middelburg. As some of this audience know, the A.I.S.I. 400 steels or straight chrome stainless steels are a significant aspect of our development work. Because of the nature of our direct chemical reduction process we are able to produce these steels most economically. As a result, we have investigated (and are still investigating) methods of welding the A.I.S.I. 430 grade (17 per cent chromium) while avoiding the characteristic embrittlement due to grain growth which one finds in this type of steel. Our best results are too sparse to be scientifically adequate but the possibility of small quantities of vanadium producing the desired effect appear to be real. Indeed, microscopy of a particular sample of weldment (patent metal: 17 per cent Cr; 0·83 per cent Va; 0·038 per cent C. Electrode: 18/8 type) showed evidence of grain refinement in the heat affected zone.

Another interesting possibility is the use of nitrogen in austenitic stainless steels—not the types referred to by Dr Muller but a manganese substituted stainless steel similar to one developed by the Germans during World War II due to the shortage of nickel. The primary constituent of this steel are chrome, manganese and nitrogen. The introduction of nitrogen eliminates the need for nickel as an austenitizer (unlike the A.I.S.I. 200 series which replaces half of the nickel content with manganese).

Grades of this steel are available commercially at the present time. However costs of conventional production are high due to the difficulty of maintaining a low carbon level at the desired level of manganese. Rolling costs are also high due to the steel's high tensile characteristics. The U.S. Steel Company has produced a steel of this type (TENELON) which although replacing nickel with manganese and nitrogen is considerably more expensive than the 18/8 chrome nickel steel which it was designed to replace. This is rather a pity, but certainly we have the means in this country by using the Bleloch reduction processes to produce such a steel at a cost significantly lower than the conventional 18/8 type.

Before I close, I would like to ask Dr Muller to provide us with some detail on lamina flow cooling of steel plate and steel bar.

C. E. Mavrocordatos: I also want to add my sincere congratulations for the excellent, almost impromptu paper, that we were treated to tonight.

This paper brought up many points, and I want, first of all, to make two clarifications. The one thing, I think, that did not transpire from the paper and the subsequent discussion, is that when these extremely fine grain sizes are talked about, one refers to the 'ferritic grain size', and not to the original 'austenitic grain size'. Am I correct?

The next item concerns the boron treated steels. Just in case a few people would rush out of this place and go to produce boron steels with carbon contents of one per cent, it must be stated that the effect of boron in increasing hardenability drops really very fast with the increase in carbon, so that by about 0·5 or 0·6 per cent, this effect practically disappears.

The third point is to give you the good news, that actually we are going to have a very major construction, very soon, in Johannesburg, in which steel to B.S.S. 968 will be used.

Author's reply to discussion

Dr Muller: There were five main questions. The one from Dr Bereza, about the protection that has to be given to the boron, i.e., the deoxidation that has to be given to the steel prior to boron addition.

One thing we do, is vacuum de-gas, although we believe that this is not really necessary, and it is quite possible, I think, in future that replacement steels, or many of them, will not be de-gassed. Ordinary deoxidation techniques, providing one ends up with a reasonably low inclusion content, should be acceptable. However, the main alloying element we use for taking care of nitrogen is, of course, titanium. The emphasis is on titanium addition for complete removal of free nitrogen prior to the boron addition.

Mr Maxwell asked about the lamina flow cooling unit. What happens, after rolling is that, one has still a sufficiently high temperature for grain growth to occur. Grain growth is inhibited in two ways, the one is to reduce the temperature at which you finish rolling, namely controlled rolling. Grain growth after rolling is now prevented by the very fast cooling effect of the steady flow of water. Most of these 'Hy-press' steels have to be coiled at temperatures of the order of 600°C. This is very low in comparison with the normal exit temperatures on such mills.

Mr Maxwell: May I rephrase my question? How doesn lamina flow cooling compare with mist cooling or spray quenching?

Dr Muller: The principle of lamina flow cooling is to pour a sufficient volume of water onto the strip at such a pressure that a continuous sheet with maximum cooling efficiency is produced.

Mr Maxwell: But this only applies to the one side.

Dr Muller: Yes, we can and do spray from the bottom, but in fact, we do find somewhat unequal hardening. However, the sections are so thin that the heat loss is very rapid even though cooling from one end, so it does not really matter very much. There are, in fact, slight structural differences between the top and bottom of 'Hy-press' strip, but it is apparently nothing to worry about.

About low-temperature working. The main effect of low-temperature working is to form a very fine sub-structure in the steel—sub grains that are normally revealed with special etching techniques or in transmission electron microscopy. As regards your question about the really low temperatures, i.e. below 700°C, I agree that the mechanism becomes simple—strain hardening.

Your question, sir, about high tensile steels.—We are now talking about a high tensile range which is of the order of a third or a half of the sort of thing you are referring to—steels that are used for stranded cables are usually high carbon steels which are given a special heat treatment, and then cold drawn to tremendously high tensile strengths—at least of the order of 100 tons per sq in., whereas we are talking of ultimate tensile strengths of the order of about 40 tons/in^2 in these steels.

The President: Thank you, Dr Muller. Now that you have answered certain questions, perhaps there may be more questions that might be flung at you. I am not going to ask any more.

Professor van Rooyen: I would like to ask Dr Muller to comment on the corrosion resistance of high nitrogen stainless steel.

Dr Muller: My information is admittedly first hand, but I am not the one who was invloved in the development. I checked particularly on this, because I somehow expected that someone was going to ask me, and I am told that, in fact, on the basis of all the ordinary corrosion tests—standard laboratory corrosion tests—there is absolutely no difference. The immediate thing you start to suspect is some lowering of corrosion resistance, but in fact, this is not the case.

A. C. Davidson: I would, perhaps, for the record, like to point out that we have made a large tonnage of B.S. 968 grade over the years, and quite a large tonnage of cor-ten, which, of course, is a different type of high strength steel. As regards one or two of Dr Bereza's remarks, I can confirm, we have made, as I said, a large tonnage of B.S. 968, and we have found, particularly in plate, that once we get half an inch thick, or thicker, we do find vanadium more suitable. We get more regular properties with it, but I must, in another way, disagree with Dr Bereza, and that is the respective amounts of vanadium and columbium that one would add in a normal structural type steel. Actually, you normally add about twice as much vanadium, as columbium. Columbium 025/03 per cent and vanadium, when used, we aim at about ·05 per cent.

If I may just ask Dr Muller a question. Where I work we have not continuous casting, and it does make a difference to our yield as to whether we use semi-killed or killed steels. We make quite a bit of both, and I would like, Dr Muller's impressions as to when one should use a killed steel. I suppose we all know that if you really want optimum toughness and good low temperature impacts, then one should use a killed steel, but it is difficult sometimes, to know where to draw the line. It does have a marked effect, of course, on our yield. With continuous casting it does not make much difference.

Dr Muller: The 'Hy-press' steel, containing the vanadium, is an Appelby Frodingham development, and it really started off as plate, which they produce in sections of some inches in thickness. A 29 ton minimum yield is achieved in plate of fairly thick section—I think of the order of two in.

As regards killed versus unkilled steels—one's practice has to be governed by the end product, plant capacity and know-how. For low quality grades where surface condition is unimportant a direct turned semi-killed steel can be more economical than a killed steel. Since our practice uses only up-hill teeming into narrow and up moulds, we find killed steels to be by far the most economical to produce.

NOTE ON SOME CHARACTERISTICS OF ANFEX

By N. W. Munro*, B.Sc. (Visitor)

SYNOPSIS

Certain disadvantages associated with the use of Anfex have been raised on previous occasions. This interim investigation shows that by loading at lower pressures the sensitivity to initiation of Anfex can be improved. Associated with this is a reduction in velocity of detonation and charge density which should lead to more desirable fragmentation.

The effect of lower loading pressure on other factors is also considered.

INTRODUCTION

Discussion at the Symposium on the use of Anfex in Underground Mining, conducted by the South African Institute of Mining and Metallurgy during May 1968† showed that there was considerable uncertainty and diversity of opinion on the characteristics of Anfex and its method of application.

Some of the disadvantages associated with the use of Anfex were:

- Inadequate sensitivity to initiation;
- Excessive fragmentation of the rock and damage to the hanging and footwalls;
- Wastage as a result of blow-back;
- Poor water resistance.

As a result of this, further investigations on the properties of Anfex have been carried out and, although these have not reached finality, it is considered that a progress review may be of interest and assistance to the mining industry.

EXPERIMENTAL TECHNIQUE

The work was carried out on a laboratory-scale where, for test purposes, the explosive was loaded into 1 in. (nominal) internal diameter steel pipes unless otherwise stated. Charging was conducted with a 1 in. (nominal) Schutte-Koerting eductor having a 0·2 in. internal diameter venturi nozzle, the Anfex being fed into the eductor from a conical hopper fitted directly above it. A 5 ft long copper loading tube with outside and internal diameters of $\frac{3}{4}$ in. and $\frac{5}{8}$ in., respectively, was fitted to the discharge end of the eductor. The remote end of the loading tube was inserted into the test pipe so that it was about 6 to 8 in. from the closed end of the pipe. The loading apparatus was withdrawn as the pipe filled, maintaining approximately the same stand-off distance throughout the operation.

REVIEW

Sensitivity to initiation

Sensitivity of Anfex to initiation was found to deteriorate when the dynamic pressure of the air to the eductor was increased. This was attributed to increasing charge density and it was found that at a charge density of about 1·05 g/cm³, which

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