SUBSTITUTION OF ALLOYING ELEMENTS BY GRAIN SIZE CONTROL OF ALLOY STEELS

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Abstract

Techniques for securing grain size control in plain carbon and alloy steels are discussed.

Fine-grained steels have many advantages such as are usually obtained through additions of alloying elements; among these are: wider heating ranges and higher grain-coarsening temperatures, relative freedom from low temperature embrittlement, higher toughness at a given strength, less trouble from warping and distortion, greater uniformity in response to heat treatment, and simplification of heat-treating cycles by elimination of treatments such as post-carburizing, refining, etc. It has been brought out in this paper that for many applications grain-refined carbon steels can replace coarse-grained low-alloy steels, excluding, of course, cases where hardenability is critical.

The uses of grain-refined steels in automotive applications have been outlined. Grain size control of low-alloy heat-treated steels is part of normal specifications in the U.S.A., but general acceptance of such specifications has been lacking in the U.K. and Europe. In India the U.S.A. grain-size specification pattern is followed slavishly by some firms, but the other firms follow the U.K. practice. A plea is put forward to rationalize this practice and evolve a uniform attitude to grain size control in the industry.

Introduction

ABOUT two decades ago a letter in the *Engineer* from the President of the Institution of Mechanical Engineers (U.K.) drew attention to his personal appreciation of the good results to be derived from controlled inherent austenitic grain size. It was complained in the U.K. in those years that the subject of controlled grain size steels had not received the attention it deserved from steel-makers and users. The position in India is much the same it was in Britain two-three decades ago so far as this subject is concerned. It would be interesting to know how many Indian purchasers of steels buy any steel to an intelligent grain-size specification. It has been estimated that 75 per cent of all killed steel is made under grain size control specifications in the U.S.A. The American engineers usually take the grain size specifications as a matter of course and they have further advanced to the position that high hardenability can naturally be secured in coarse-grained steels, but that it could also be conferred on fine-grained steels by manipulation of manganese content and other common deep-hardening elements.

They have also regarded that relative scarcity of alloying elements has required the adjustment of all steels to the simplest possible compositions. It is time that in India this subject is examined rationally.

Unalloyed mild steel is a common commodity and is used extensively for a multitude of purposes. One of the most noteworthy developments of the last two decades is that toughness, as judged by the impact test, is related to steel-making, particularly its mode and extent of deoxidation. The effect is more pronounced in plain carbon and low-alloy steels than in high-alloy steels. While other physical properties remain almost constant, the impact toughness and non-susceptibility to various forms of embrittlement are immensely enhanced by securing a fine, inherent austenitic grain size in steels with the exception of cases where deep-hardenability is the over-riding criterion.

Although the theories for the mechanism of grain size control to prevent coarsening of the austenitic grains on heating are still being thrashed out, open-hearth steels have been made to grain size specifications for the past thirty years, and most producers are in general agreement about the methods required for effecting grain size control of steel.

In general, grain size control consists of adding enough aluminium to fully deoxidize the metal and ensure a small definite amount of aluminium in solid solution. Naturally, the amount of residual oxygen in the steel after other deoxidizers are added affects the amount of aluminium necessary to make the steel fine-grained. An excess of 0·020-0·050 per cent aluminium ensures an inherent fine austenitic grain size. Several factors must be considered in deciding on the amount of aluminium to be used, viz. carbon content, melt temperature, state of deoxidation and silicon content of the bath, the manner and the form of aluminium used, etc. The amount of aluminium necessary to control the austenitic grain size will vary for different steel-making procedures and practices. In a certain plant 1·5 lb. of aluminium per ton would be required for a 0·15 per cent carbon heat, and 1·0 lb. per ton for 0·60 per cent carbon. For the same carbon contents another plant would require 2·0 and 0·85 lb. per ton respectively. Generally, lower the carbon content, the greater the amount of aluminium required for the grain size control. Less aluminium is required for a steel of 0·25-0·30 per cent silicon than one of 0·15-0·20 per cent silicon. The state of deoxidation at tap is indicated by residual silicon of the bath.

For ladle additions shot aluminium is usually used for grain size control. The addition should be made during the early state of tap to ensure complete solution and to avoid excessive losses by oxidation. The last ingots of some open-hearth heats thus treated may show a tendency toward grain coarsening. This is due to oxidation of the aluminium in the steel at the interface between metal and the highly basic oxidizing slag. The easiest remedy is to add shot aluminium to the last few molds, but this practice sometimes results in dirty steel. The more difficult but most satisfactory method is to control the amount, condition and viscosity of the slag on the metal in the ladle, so that it chills and becomes relatively inactive.

Elements other than aluminium can also be used for grain size refinement, such as vanadium, tungsten, titanium, zirconium and columbium, but their use is costly. The common alloying elements also have a slight effect, chromium steels being more difficult to make fine-grained than nickel, molybdenum or vanadium steels. Thoroughly deoxidized, coarse-grained steels are difficult to make. In the making of well-killed coarse-grained steels temperature and the state of deoxidation have to be regulated using silicon-based deoxidizers for killing the steel — the minimum of aluminium or titanium should be employed in these cases.

Effect of Austenitic Grain Size on Properties of Steels

One of the most important effects of austenitic grain size is its adverse influence on hardenability. In that old classic paper of McQuaid-Ehn published in 1922, it was observed that steels which hardened uniformly on quenching after carburization could be distinguished structurally from those that did not and developed soft ' abnormal ' spots. On further analyses it was found that good hardenability was conferred by coarse austenitic grains, fine undivorced pearlite; pearlite contiguously located to carbide net-work of thin continuous pattern whilst poor hardenability followed fine austenitic grains, coarse and divorced pearlite, and discontinuous and coarser carbide net-work; the former was termed ' normal ' and the latter ' abnormal ' steel.

The general effects of austenitic grain size upon steel behaviour are given below:

Property	*Austenite grain size*	
	Coarse	*Fine*
Hardenability	Deeper	Shallower
Tensile strength (steel normalized)	Higher	Lower
Ductility (steel normalized)	Lower	Higher
Impact strength	Lower	Higher
Carburized structure (McQuaid-Ehn test)	Normal	Abnormal
Machinability, rough	Improved	Impaired
Machinability, finish	Impaired	Improved
Transformation temperature	Lower	Higher
Quenching cracks	Frequent	Very rare
Grinding cracks	More susceptible	Less susceptible
Distortion in heat-treating	Greater	Less

Effect of Alloying Elements on the Austenite Grain Size

In general, those elements added to steel which combine with carbon to form carbides, or with oxygen to form a finely divided dispersion of oxides, tend to enhance resistance to grain growth[1]. The generally accepted explanation for this effect is that the carbides or oxides of these elements are capable of remaining both undissolved and unagglomerated over a considerable temperature range, and as long as they remain in this optimum condition, they ' somehow ' provide an effective obstruction to grain growth. As soon as they dissolve, or coalesce to form larger particles, they cease to be effective inhibitors, and the grains then grow rapidly, often attaining a larger size than that observed at the same temperature in unalloyed steels. Elements such as nickel or copper which do not form carbides do not seem to affect the grain size markedly.

Austenitic Grain-refined Steels to Replace Low-alloy Steels and Grain-refined Low-alloy Steels to Replace High-alloy Steels for Optimum Applications

The first result of the recognition of the relations between aluminium additions, inherent austenitic grain size and physical characteristics was that an important factor had been established which required due recognition.

When production methods of controlling the grain size were developed, it became possible to produce either fine or coarse-grained steels as required, and variations in physical behaviour were, to a large extent, eliminated. Investigations of the differences between fine and coarse-grained steels then led to the selection of one type for some purposes and the other for other purposes. Coarse-grained steels were recommended for easy machinability, deep-hardening and higher strength in a given condition, while fine-grained were favoured because the heating temperature was not so critical, there was less danger of cracking or warping during hardening, a greater toughness was obtained in association with a given strength or hardness, and less austenitic grain growth took place during carburizing. The difference in machinability between fine and coarse-grained steels is not great, and could probably be overcome by altering the normalizing treatment that precedes machining; the shallower hardening of fine-grained steels may be counterbalanced by increasing the manganese content or by adding other elements. The view has gained ground that fine-grained and coarse-grained steels are not just different varieties of the same steel, but that the fine-grained are actually materials of better quality, to be preferred for all uses involving heat treatment, and the composition and treatment altered accordingly. The effects of grain size control are most marked in carbon steels and those containing small amounts of alloying elements. As the content of such elements increases, the influence of strong deoxidation becomes less marked because the alloying elements exert the same kind of effects as it does. The opposite is also true, and the production of fine-grained steels by strong deoxidation leads to many of the advantages hitherto obtained with alloying elements, e.g. wider heating range, higher toughness in association with a given strength, less trouble from warping and cracking, and the elimination of refining treatments after carburizing. Thus fine-grained carbon steels may be used in place of coarse-grained low-alloy steels and fine-grained low-alloy steels in place of coarse-grained high-alloy steels. This is only possible, however, where the greater depth of hardening obtainable with alloying elements is not required. When this is the chief factor, the change from coarse-grained to fine-grained cannot be accompanied by a reduction in the content of alloying elements. However, the capacity of steel to harden *at the surface* is very well conferred by small additions of aluminium which confer on it the property of a high grade alloy steel as regards toughness.

Work on this important subject has already been done in India[2] on a fairly extensive scale both from theoretical and practical viewpoints. Fair amount of data are available on this subject of austenitic grain-refinement vis-à-vis improvement in physical properties of different categories of Indian steels. This work is being continued at the National Metallurgical Laboratory.

Not much work has been done on the mechanical properties of coarse and fine-grained alloy steels of heat-treatable grade. The authors' results are reproduced here (Table 1) to illustrate the improved impact toughness that can be obtained by grain size control in Ni-Cr steels which do not contain molybdenum. It will be noticed that grain-refinement has tempering effects not only on impact toughness, but also on temper

TABLE 1

HEAT TREATMENT	ELONG., %	REDN. OF AREA, %	YIELD PT., tons/sq. in.	MAX. STRESS, tons/sq. in.	AV. IZOD IMPACT VAL., ft.-lb.	MCQUAID-EHN GRAIN SIZE (A.S.T.M.)
E.H.14*						
Annealed at 900°C.	18·75	42·9	Not sharp	55·40	8·3	3-4
Oil-quenched at 850°C., tempered at 600°C. and slowly cooled	18·75	48·9	do	61·77	10·0	3-4
E.H.15†						
Annealed at 900°C.	21·87	50·6	do	53·60	16·0	7-8
Oil-quenched at 850°C., tempered at 600°C. and slowly cooled	19·92	51·5	do	61·17	17·0	7-8

*E.H.14: C, 0·40; Mn, 0·71; Si, 0·23; S, 0·03; P, 0·02; Ni, 3·33; Cr, 0·87 per cent; and Al, nil.

†E.H.15: C, 0·40; Mn, 0·70; Si, 0·24; S, 0·03; P, 0·02; Ni, 3·30; Cr, 0·86; Al, 0·029 per cent.

Izod Impact and Hardness Values of Specimens Quenched After Tempering at 600°C.

REF. NO. OF STEEL	MCQUAID-EHN GRAIN SIZE	AV. IMPACT VAL. AFTER TREATMENT, ft.-lb.		V.P.H. NO. AFTER TREATMENT		SUSCEPTIBILITY RATIO
		A	B	A	B	
E.H.14	3-4	47	46	290	285	4·7
E.H.15	7-8	55	52	295	287	3·2

embrittlement through a lowering of the susceptibility ratio.

Hugh O'Neill[3] demonstrated the excellent effect of grain size refinement both in plain carbon and alloy steels for railway applications, such as connecting and coupling rods. He showed that manganese-molybdenum steels of controlled inherent fine grain size furnished uniformly satisfactory results. Plain carbon steels of inherently fine grain size yielded the same mechanical test values as low-alloy steels and gave satisfactory performance both during manufacture and in service as coupling rods. Their impact Izod values were notably high. Where steels are required to possess high impact toughness values, steels of fine grain size are superior even if these are of shallow-hardening type. Inherently fine grain size steels resist coarsening at forging temperatures.

To date, there has been little production of grain-controlled steels in India, despite the fact that such steels undoubtedly extend the range of useful applications of plain carbon and low-alloy steels.

Aluminium in small quantities is soluble in ferrite and it greatly improves the impact toughness of steels particularly at low temperatures. While no clear picture of the mechanisms whereby aluminium brings this about is available, the practical fact is most definitely established. The position that additions of face-centred lattice metals to ferrite improves the impact resistance of steels at low temperatures is not always tenable; the additions of copper in amounts as are soluble in ferrite often cause a very confused picture. Much more theoretical research is necessary to establish the causes leading to the above practical results.

Controlled Grain Size Steels for Automotive Purposes

Considerable amount of work has been done in the U.S.A. to establish the uses of grain-controlled steels and of grain size of different alloy steels employed in automotive applications — maximum uses of grain-refined steels are for case-carburizing uses.

Table 2 gives, after McQuaid [*T.A.S.M.*, **22** (1934), 1017-1937], commonly used automotive steels and usual McQuaid-Ehn grain size requirements.

There has been lately some spurt of work for steels for low-temperature service and in this connection aluminium-treated alloy steels have been investigated into, particularly Cr-Cu-Ni series. Walter Crafts and C. M. Offenhauer have done excellent work on the subject[4] and their findings are based on the results that the combination of Cr, Cu and Ni appeared to permit the lowest transition temperature with a minimum alloy content if the aluminium content is raised to a level approximately 0·20 per cent. There appear to be no difficulties involved in the fabrication of these steels and significant saving of alloy can result consistent with successful applications at temperatures as low as —100°C.

Fig. 1 depicts the results of these authors.

Aluminium additions are commonly employed to lower the tough to brittle transition

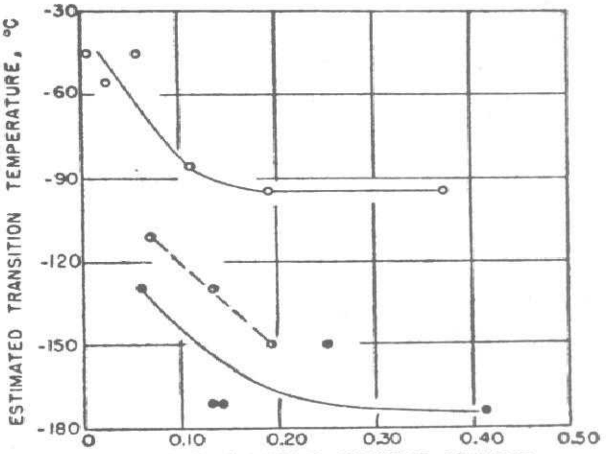

FIG. 1 — EFFECT OF SOLUBLE ALUMINIUM ON THE ESTIMATED TRANSITION TEMPERATURE OF SOME EXPERIMENTAL STEELS

○, Plain carbon; ◑, Cr-Cu-Ni steel; ●, Modified Cr-Cu-Ni steel

TABLE 2

STEEL	GRAIN SIZE RECOMMENDED
(a) Plain carbon not heat-treated parts: SAE 1112, SAE 1010, SAE 1020, etc., SAE X-1315	Coarse for maximum machinability and best cold-heading properties. Fine when subjected to shock loads or occasional severe overstress.
(b) Plain carbon heat-treated uncarburized parts: SAE 1025, SAE 1040, SAE 1050, etc., Ford EE, EEE, etc.	Generally fine-grained, shallow-hardening type. When oil-hardened to high Brinell use coarse grain type. Coarse grain in very heavy parts such as large truck front axles. Medium grain in passenger car front axles.
(c) Plain carbon case-hardening type: SAE 1010, SAE 1020, SAE X-1315	Fine grain for minimum distortion. Coarse for machining and hardening. Generally recommended fine as possible consistent with satisfactory surface hardness. Used in camshafts, small gears, some differential parts, brake parts, washers, etc.
(d) Plain carbon high carbon type: SAE 1060, SAE 1095, etc.	Flat springs, valve springs, coil springs. Fine grain best to avoid stress concentration. Bumper bar stock medium grain size to coarse for oil-hardening.
(e) Plain carbon, high manganese with or without high sulphur: SAE 1340, SAE 1360, etc.	Used in many important parts. Fine grain preferred. Depends on analysis, quench, etc. Not commonly specified.
(f) Low carbon, low-alloy, case-hardening steels: SAE 2015, SAE 2115, etc. Chromium-nickel, Vanadium-gear steel C.N.V.	Fine grain for gears. Danger of trouble with surface soft spots if too fine and abnormal. For heavy parts, coarse grain. For direct quenching, fine grain preferred.
(g) Low carbon, medium alloy types: SAE 3115, SAE 6115, SAE 4615, SAE 2315, etc. Carburizing grade	For gears and bearings, fine-grained best. Fine grain for direct quench. Coarse grain for heavy sections for maximum core properties. For maximum machinability with increased distortion, coarse grain preferred unless specially normalized.
(h) Low carbon, high alloy type: Case-hardening 3½ per cent Ni. Molybdenum: SAE 2512, SAE 3300, SAE 3400, Krupp, etc.	Used for truck and bus gears and very heavy-duty case-hardened parts. Fine grain in all applications.
(i) Medium carbon, medium alloy: SAE 3130-3140, SAE 4130-4140, SAE 5130-5140-1550, SAE 6130-6140-6150	Used for passenger car and light truck axle shafts, arms, knuckles, some connecting-rods, crank, oil-hardened gears, etc. Should be fine-grained in all applications where so-called toughness is important. In heavy sections where deep quench is required medium or coarse grain is best.
(j) Medium carbon, high alloy steel: SAE 3240, SAE 3330-3340, SAE 3335, SAE 3440, Cr-Ni-Molybdenum, etc.	Used for heavy-duty gears, axle shafts, highly stressed parts. Always fine grain when used for above parts.

temperature ranges of steels. Al exercises some toughening effects besides that of grain refinement. The probable role of grain size control has recently been explained by Chatterjea and Nijhawan[5] who regard, in finely divided grain boundary precipitations of aluminium nitride, the constituent which inhibits grain growth.

The major uses of grain refinement have shown in the low-alloy automotive types of heat-treatable grades of steels. Fine grain size in low-alloy steels is often a good requisite even if it is not specified, since it ensures low coarsening temperature range during heat treatment and adequate toughness. Some hardenability loss may occur, but this can be adjusted with higher manganese contents. So far as India is concerned, manganese should not present any problem.

The effects of small additions of aluminium on alloy steels were investigated by M. Signora[6] on nickel-chrome structural steels (C, 0·31 per cent; Mn, 0·37 per cent; Si, 0·35 per cent; S and P, each below 0·009 per cent; Ni, 2·5 per cent; Cr, 0·74 per cent; and Cu, 0·18 per cent) who concluded that additions of 0·01 per cent conferred fine McQuaid-Ehn grain size independent of pouring temperature.

Transformation Characteristics of Coarse and Fine-grained Alloy Steels

Transformation characteristics of coarse and fine-grained alloy steels were exhaustively studied by M. S. Wang[7] and his major findings are given below:

1. Coarse and fine-grained steels showed different isothermal transformation characteristics. In the pearlite range the rate of transformation is accelerated, in the bainite range the reaction is retarded in fine-grained steels, but in the martensitic range grain size has no effect.
2. The effect of grain size applies to both plain carbon and alloy steels.
3. The period of incubation is caused by the thermal stress set up during quenching which stabilizes the austenite and it is a period of relaxation of this stress.
4. On the basis of thermal stress theory the difference in the reaction rate of coarse and fine-grained steels can be explained.

Wang further studied steels of coarse and fine-grained to evaluate the difference, if any, of the isothermal transformation characteristics. The fine-grained steels were made by means of small additions of aluminium and each pair of steels were as nearly identical as possible in composition and preliminary heat treatment. In the series of steels studied, the fine-grained steels showed a more rapid reaction in the pearlite range than the coarse-grained steels. This is in accordance with the general accepted theory that the fine-grained steels possess more nuclei (boundary nuclei probably) in the temperature region where the process of nucleation and growth is suspected to take place. For the martensite range, no appreciable difference of the reaction rates with coarse-grained and fine-grained steels has been noted. For the bainite range, however, the fine-grained steels showed a slower rate of reaction. This is contradictory to the results of other workers.

Figs. 2 and 3 depict the transformation characteristics of a SAE 4140 steel in the fine-grained and coarse-grained conditions respectively. So far as the upper bainite

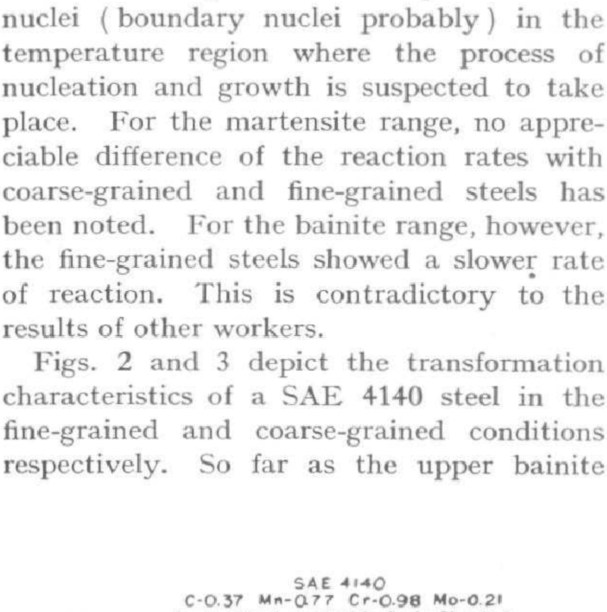

FIG. 2 — ISOTHERMAL TRANSFORMATION DIAGRAM OF SAE 4140 STEEL, IN FINE-GRAINED CONDITION AUSTENITIZED AT 1550°F. (From *Atlas of Isothermal Transformation Diagrams*, U.S. Steel Corp.)

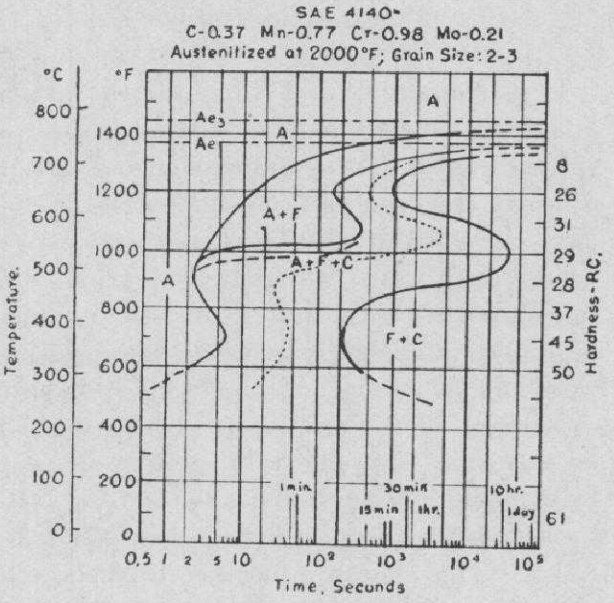

FIG. 3 — SAME AS FIG. 2, BUT STEEL IN COARSE-GRAINED CONDITION AUSTENITIZED AT 2000°F.

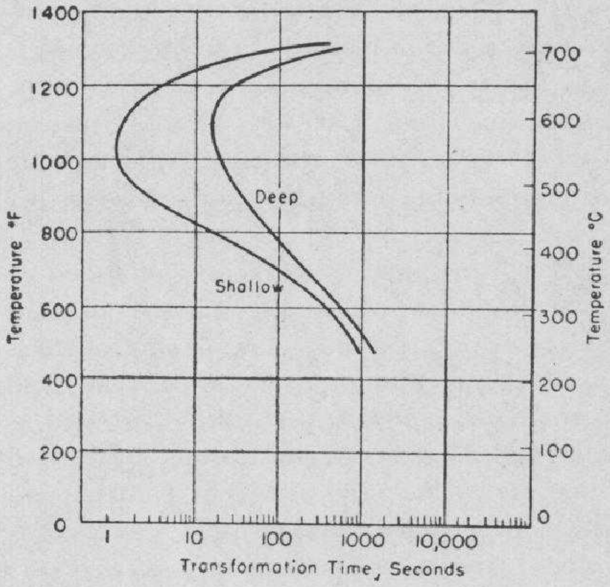

FIG. 4 — TIME INTERVAL FOR 50 PER CENT TRANSFORMATION AT TEMPERATURES SIGNIFICANT IN HARDENABILITY FOR A SHALLOW AND A DEEP-HARDENING LOW-ALLOY STEEL [BAIN (38)].

region is concerned, the results of Wang are contradictory to those depicted in Figs. 2 and 3. In these two figures the upper ' nose ' at about 1200°F. (650°C.) represents formation of pearlite, which presumably nucleated at the grain boundaries, and it will be noted that the time for transformation to pearlite was two to four times as long in the coarse-grained material as in the fine-grained material. On the other hand, the lower ' nose ' at about 900°F. (480°C.) represents upper bainite which forms in a manner other than by nucleation at the grain boundaries. In the case of this lower ' nose ' the times for transformation are almost identical for the fine-grained and the coarse-grained conditions. Time interval for 50 per cent transformation at temperature significant in hardenability for a shallow and deep-hardening low-alloy steels is shown after Bain in Fig. 4. It is shown that the prior austenite grain size has a marked effect on the response of the steel to a given treatment. Hardenability is directly related to austenite grain size — the coarser grains having a lower reaction or critical cooling rate and, therefore, more easily cooled below the knee of the ' S ' curve so that the martensite transformation can take place.

Aluminium as an Alloying Element in Tool Steel

An unusual application of aluminium as a means to conserve tungsten and other alloying elements was recently reported by Mitsche and Onitsch[8] and by Prosvirin and co-workers[9]. The results of lathe tests reported by the first-named investigators indicate that the addition of 0·5 per cent aluminium to Cr-Mo-V tool steels is equivalent to the addition of 1·3 per cent tungsten. It was also claimed on the basis of machine-shop tests that a Cr-Mo-V tool steel with 1·3 per cent tungsten and 0·5 per cent aluminium was equal in lathe performance to a similar tool steel with 2·5 per cent tungsten and approached the performance of a 10 per cent tungsten steel in drilling operations.

Aluminium-containing low-alloy tools were found by Mitsche and Onitsch[8] to be very sensitive to slight variations in heat treatment. A double tempering at 1040°F.

(560°C.) was necessary for the aluminium-containing steels instead of the single tempering used for aluminium-free tool steels. Quenching from 2300°F. (1260°C.) instead of 2245°F. (1230°C.) decreased the tool life of aluminium-containing steels by 50 per cent.

Prosvirin and co-workers[9] published a monograph in which they report in considerable detail results of tests on tool steels in which aluminium (up to 3·0 per cent) and nitrogen (up to 0·20 per cent) were used as alloying elements. The results permitted them to reduce the tungsten content and develop so-called 'substitution' tool steels which gave a very satisfactory service performance. Table 3 lists the chemical composition of some of their experimental steels in which chromium, vanadium, tungsten, aluminium and nitrogen were varied and on which tool-life tests were made for comparison with a standard high-speed steel.

Position in India

It is estimated that three-fourths of all killed steel made in the U.S.A. are made of specification requiring grain size control. It is worth querying the position in India today. A word of caution is necessary. We would qualify the adherence to grain size specifications by the restriction that it must be applied intelligently. We would repeat the word intelligent since cases are known where expensive alloy steels have been rejected because the McQuaid-Ehn grain size was experimentally determined to be A.S.T.M. No. 6 whereas that specified was A.S.T.M. No. 7. This slavish adherence to the specifications is to be strongly discouraged. It should be realized that it is now only possible to produce inherent coarse or inherent fine grain size steels at will; intermediate grain size cannot be so definitely commandeered as yet.

TABLE 3

GROUP	DESCRIPTION	STEEL NO.	COMPOSITION, %							
			C	Mn	Si	Cr	V	W	Al	N
A	Tungsten-free steel	11	1·04	0·35	0·14	4·91	1·52	—	0·53	0·02
		12	0·86	0·37	0·18	5·02	1·29	—	0·51	0·02
		13	1·05	0·38	0·36	4·91	1·33	—	0·51	0·02
		23	1·03	0·40	0·31	5·14	2·50	—	0·98	0·28
		24	1·09	0·38	0·30	4·99	1·95	—	1·40	0·05
B	Tungsten-free steels with increased C, Mn and Cr contents	28	1·55	1·22	0·36	6·55	3·55	—	1·14	0·07
		29	1·47	1·18	0·59	6·32	3·50	—	1·31	0·07
		32	1·53	0·81	1·03	6·22	3·30	—	0·64	0·05
		30	1·45	0·96	0·51	8·50	3·41	—	1·34	0·09
		31	1·32	0·96	0·54	10·31	3·45	—	1·27	0·06
C	Low-tungsten steels	14	0·86	0·38	0·12	4·88	1·52	1·86	0·30	0·08
		15	0·99	0·40	0·23	4·89	1·52	2·76	0·30	0·09
		16	0·92	0·38	0·21	4·79	1·92	3·61	0·71	0·07
D	Low-tungsten steel with increased Cr and Mn	33	1·74	0·96	0·78	8·70	3·10	1·32	1·34	0·09
		34	1·59	1·03	0·86	8·01	3·37	2·63	1·29	0·09
		35	1·72	0·68	0·43	4·67	2·70	3·78	0·50	0·05
		36	1·49	0·56	0·91	11·00	3·43	3·41	1·78	0·05

The major application of grain-controlled steel is in the low-alloy automotive heat-treatable steels. In Britain and Europe, acceptance of grain size specification classes has not been as general as in the U.S.A., with the position in this country that those firms adhering to British specifications tend to totally overlook the grain size requirements of the steels they employ. The authors would, however, tend to take the view that grain size control specifications in low-alloy steel would appear to be necessary so long as its application follows intelligent and sensible lines. It would also appear to us that the American system of grain size specifications ensures somewhat less alloy content for a given quanta of physical properties in steel than it would be necessary in the U.K. or Europe. The position so far as India is concerned now needs serious and rational study in the present stage of our industrial development.

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