

THE ENGINEER AND GRAIN-SIZE CONTROL IN STEEL

By

B. R. NIJHAWAN, Ph.D. (Sheffield), B.Sc., (Met.),
Inspecting Officer (Research)
Metallurgical Inspectorate,
TATANAGAR.

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INTRODUCTION.

The object of this short paper is to invite the attention and arouse the interest of Engineers to a very useful development in steel metallurgy, of recent growth, namely "Grain-size control in steel", which originated in the United States of America and is now actively pursued all over the world particularly in America and the United Kingdom. A voluminous literature has been compiled on the subject by various scientific bodies. It is hoped that this summarised survey on "Grain-size control in steel" will briefly present the essential data on the subject to the Engineers without their having to resort to a comprehensive and detailed study of this field of steel Metallurgy—often a discouraging task to non-metallurgists.

It is further hoped that a study of the data will initiate the applications of the developments in "Controlled grain-size" to various types of Indian steels both by the steel makers and users in this country.

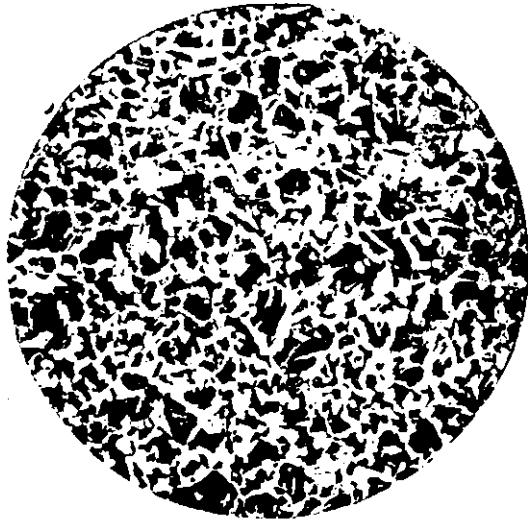


FIG. 1.—Normal structure of low Carbon Steel.

Magnification 100 Dia.

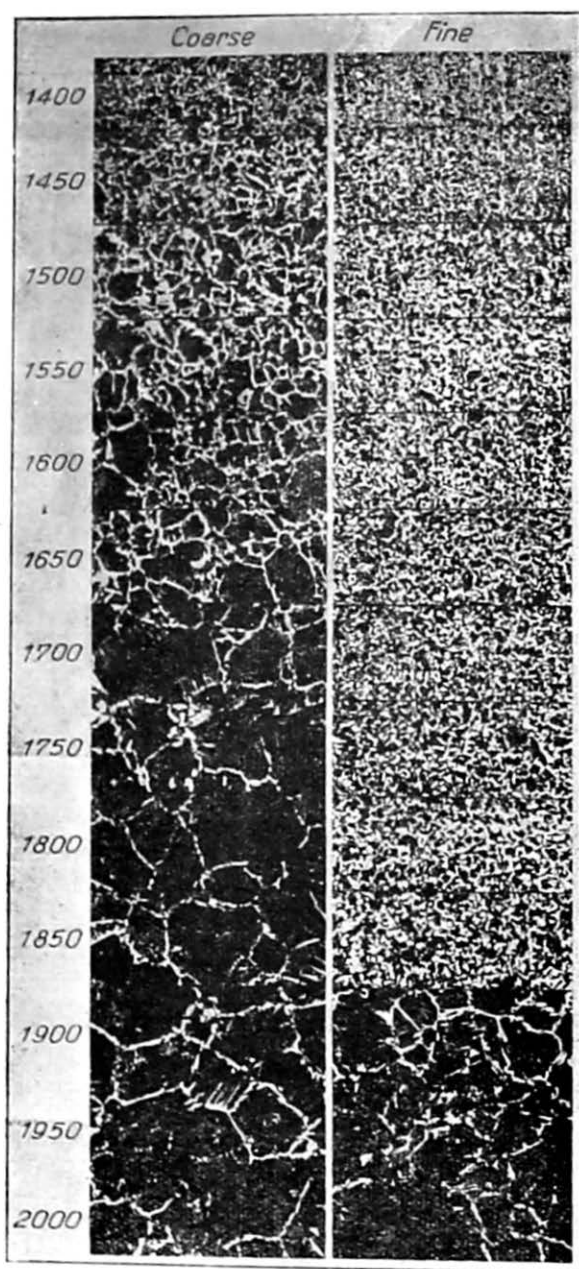


FIG. 2. Composite Micrographs showing the actual grain sizes of the Coarse and Fine-grained types after normalizing at Temperature shown in degrees Fahrenheit. (P. Schane Jr.)

“ THE ENGINEER AND GRAIN-SIZE CONTROL IN STEEL. ”

What is Grain Size ?

As is generally known, a mass of metal is made up of “ Crystalline aggregates ” or Crystalline Grains ” or Simply Grains. In a general way, the three dimensional size of these metal grains affects the metal's behaviour to heat-treatment, its properties and service performance. When a steel ingot is cast the metal solidifies in a certain grain or dendritic pattern depending upon the size, shape and nature of the mould, the rate and the temperature of pouring, the fluidity of the metal etc. This original cast or dendritic grain pattern is then altered into the rolled, forged or pressed grain structure resulting from hot-soaking and mechanical work. The rolled or mechanically worked grain-structure is, in most cases, re-oriented into its normal distortion-free pattern through high temperature treatments termed “ Normalizing ” or “ Annealing ” which also tend to relieve the metal of any residual mechanical stresses. This finished grain-structure is thus ready to go into service. A typical example of mild steel in this normal condition is shown in Fig. 1.

Besides this grain-structure, there is another high temperature grain size of steel which is termed “ Inherent Austenitic grain size ” or simply “ Inherent grain size ”. For plain carbon steels there is a temperature range between about 720° C. to 880-890° C. which is called its “ Critical temperature range ”. When heated to this “ Critical range ”, the steel undergoes an allotropic modification from what is termed as α type-Ferrite to γ type-Austenite and vice-versa from Austenite to Ferrite on cooling through the ‘ Critical range ’. In heating through this range, the metallic grains get rid of their mechanical distortion and tend to change into their normal structure or in short re-orient themselves into normal grains. Besides, certain changes in the solubility of carbon or iron-carbide (the form in which the carbon exists in steel) take place during its passage through the critical range. Just below the critical range the carbon is in solution in α ferrite to only about 0.04% and the rest of it exists in loose pearl like form, termed in metallographic language as “ Pearlite ”. As the steel passes through the critical range more and more of the Pearlitic carbon is absorbed into the iron and finally, above the critical range, the carbon is wholly in solution in γ iron to form the Austenite. Thus, on passing through the critical range, the metal undergoes certain constitutional changes and at the end of it, is born a new grain structure—the Austenitic grain structure.

Different steels possess different initial Austenitic structures. This Austenite grain structure develops or coarsens gradually as the metal is heated above the “ Critical Range ”. No two steels will exhibit the same Austenitic grain coarsening characteristics above the “ Critical temperature range ”. Some steels will show more Austenitic grain coarsening, and some less. This Austenitic grain-coarsening characteristics is, what is termed as “ Grain-size ” control in its latest metallurgical sense. It depends upon the chemical composition of the steel and certain rather exacting features of steel making, notably the mode of deoxidation and the final residual deoxidant in solution in the cast steel. Besides other elements Aluminium is a strong deoxidant. Strong deoxidation of the steel with Aluminium tends to raise the temperature at which austenite grain growth takes place on heating above the “ Critical Range ”. In a steel to which a small amount or no Aluminium has been added, austenite grain growth takes place readily at a temperature not far above the critical range and progresses rapidly as the temperature rises. The former is termed an “ Inherent Fine Grain ” or simply “ Fine Grain ” steel and the latter as an “ Inherent coarse grain ” or simply “ Coarse Grain ” steel. These new and specific meaning of the grain

size terminology should be clearly borne in mind since this inherent or Austenitic grain size may not necessarily have any relationship with the grain size of the steel as it goes into service. The room-temperature grain size of a steel is influenced mostly by the conditions of casting and the subsequent thermal and mechanical work to which the steel is subjected; whilst the inherent or Austenitic grain size is influenced by the deoxidation practice of the steel making and particularly by the residual Aluminium in solution in the steel. There may be two steels, one showing a fine room temperature grain structure and the other coarse. Yet, it is possible that the latter if it contains suitable additions of Aluminium would resist grain coarsening above the critical range and would thus be an "Inherent fine grain" steel in relation to the former which, if it were not suitably deoxidized or what is termed as "Killed" with Aluminium, would show great propensity to grain growth at relatively low temperature above the critical range and would thus be an "Inherent coarse grain steel". On the other hand, if there are two types of steel, one fine Austenitic grained and the other coarse Austenitic grained size, both identically worked and subjected to identical heat treatments or say normalised (i.e. air cooled from just above the critical temperature range), then their normalized grain structures will likewise tend to be fine and coarse in the case of the former and the latter respectively. The normalized grain structure in the two cases, will not however, reveal the actual Austenitic grain size prevailing above the critical temperature range. To reveal this actual Austenitic grain size, various methods have to be employed and will be referred to later. The composite Micro-photograph Fig. 2 illustrates the difference in grain-coarsening characteristics between coarse and fine grained steels. The two steels had been heated up to progressively higher temperatures and air cooled. Their structures were then examined. The coarse Austenitic grained steel started to coarsen at about 1450°F., whereas the fine grained type exhibited the same fineness of structure upto 1900°F.

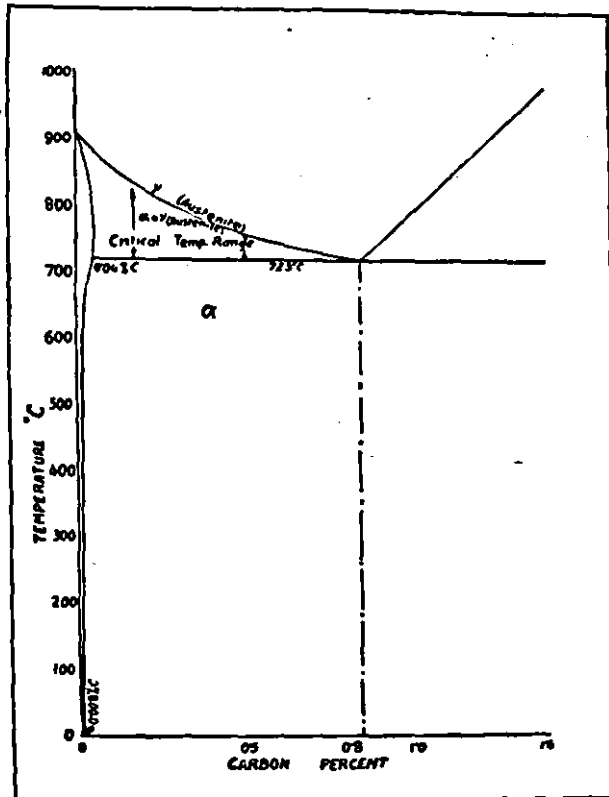


Fig. 3. Diagram showing the critical temperature range for Plain Carbon Steels.

Fig. 3 shows a diagrammatical sketch showing the critical temperature range for plain carbon steels.

It has been shown that in a properly deoxidized plain carbon steel a final residual content of 0.03 to 0.04 % of Aluminium in solution confers upon it an "Inherent fine Austenitic grain" structure. Most of the Engineering steels examined by this Inspectorate have shown upto a maximum of 0.003 % Aluminium in solution.

The earlier notions that aluminium addition to steels result in detrimental non-metallic inclusions have now lost ground. It is apparent that the objection to Aluminium additions arose from the fact that these had been employed as dope in the past to condition over-oxidized and badly worked heats of steels and under these conditions gave rise to large aluminium inclusions. If, however, the heat is properly worked and deoxidized, the aluminium additions are very useful in imparting an "Inherent fine grain" quality to the steel.

DIFFERENCES BETWEEN COARSE AND FINE AUSTENITIC GRAINED STEEL.

To an Engineer's mind, the question will naturally occur that if the new conception of "grain size" refers to its grain-coarsening characteristics at high temperatures above the "critical range", what relation has it with the physical properties of the metal with which he is mainly concerned to determine its suitability for a particular purpose. The answer is simple. The high temperature grain-growth characteristics greatly influence the physical properties and the response of the metal to various heat-treatments particularly that of hardening. Besides, the resistance to grain growth at high temperatures above the critical range renders unnecessary certain heat-treatment cycles following case-carburization. The inherently fine grain steels possess certain marked favourable physical properties compared to the inherently coarse grained type, the most outstanding of which is their high impact toughness. As will be shown later, the fine-Austenitic grained steel eliminates the necessity of its being alloyed with some expensive elements to develop certain physical properties. Furthermore, low alloy inherent fine grained steels can economically replace highly alloyed costly steels.

The knowledge of Austenitic grain size is of little value unless its effect upon the physical properties of steel are known and applied in service. The following summarizes the influence of grain size variations on the physical properties and characteristics of steel.

I. IMPACT AND TENSILE PROPERTIES.

From the results of numerous investigations it is now well established that the fine grained steels possess much higher impact values than coarse-grained types of identical chemical composition and tensile properties. In normalized condition the fine grained steels have a slightly lower ultimate tensile strength, a higher elongation and a substantially higher notched-bar toughness. This is illustrated in 0.40% Carbon steels as below:—

Grain size.	Tensile strength tons per sq. inch.	Elongation %	Izod Impact.
Coarse ..	44	22	15 ft. lbs.
Fine ..	40	28	55 ft. lbs.

When inherently fine and coarse-grained specimens of the same steel are quenched from above the critical temperature range and tempered under the

same conditions, the former have a slightly lower tensile strength, a slightly higher elongation and reduction in area and a substantially higher notched-bar toughness. Carpenter gives the following results in the case of a 0.5% carbon steel oil quenched from 840° C. in the form of 1.1/8" diameter bar and tempered at 650° C. :—

Grain size.	Tensile strength tons/sq. inch.	Yield stress tons/sq. inch	Elongation	Red of A %	Izod impact ft. lbs.
Coarse ..	53.1	37.0	25.5	59.2	16.7
Fine ..	50.0	35.1	27.0	61.6	76.0

The impact toughness of the fine grained steel was distinctly superior. When this fine grained steel after quenching was tempered at 600° C, it gave the following values :—

Tensile strength tons per sq. inch.	Yield stress tons/sq. inch.	Elongation %	Red of A %	Izod Impact ft. lbs.
53.4	..	26	57.2	54.7

The tensile strength was the same as that of coarse grained steel but Izod value was much higher. Scott has shown that when the coarse and fine grained types of the same steel are heat-treated to give the same hardness values say between 400 and 600 V.P.H.No., the toughness of the fine-grained type is much greater than that of the coarse-grained.

Grain size.	Hardness value.	Izod impact value ft. lbs.
Fine	440	37
Coarse	440	8
Fine	600	25
Coarse	600	6

Davenport and Bain took one steel, heated to different temperatures above the critical temperature range to develop different Austenitic grain sizes and quenched from a uniform temperature and tempered at different temperatures to give a Rockwell hardness of C 50. The results are given below :—

Heating temperature.	Quenching temperature.	Austenitic grain size develop at the heating temperature.	Hardness C Rockwell.	Impact ft. lbs.
760°C	760°C	Very fine	50	11
845°C	..	Fine	50	3
930°C	..	Coarse	50	2
1010°C	..	Very coarse	50	1

The results show that the Austenite grain size established during heating greatly influences the toughness of the heat-treated steel. The author obtained the following values in the case of 0.20% carbon steels one treated with Aluminium and the other Aluminium-free both in the normalized state :—

Izod Impact Average.

Fine grain	82.4 ft. lbs.
Coarse grain	37.6 ft. lbs.

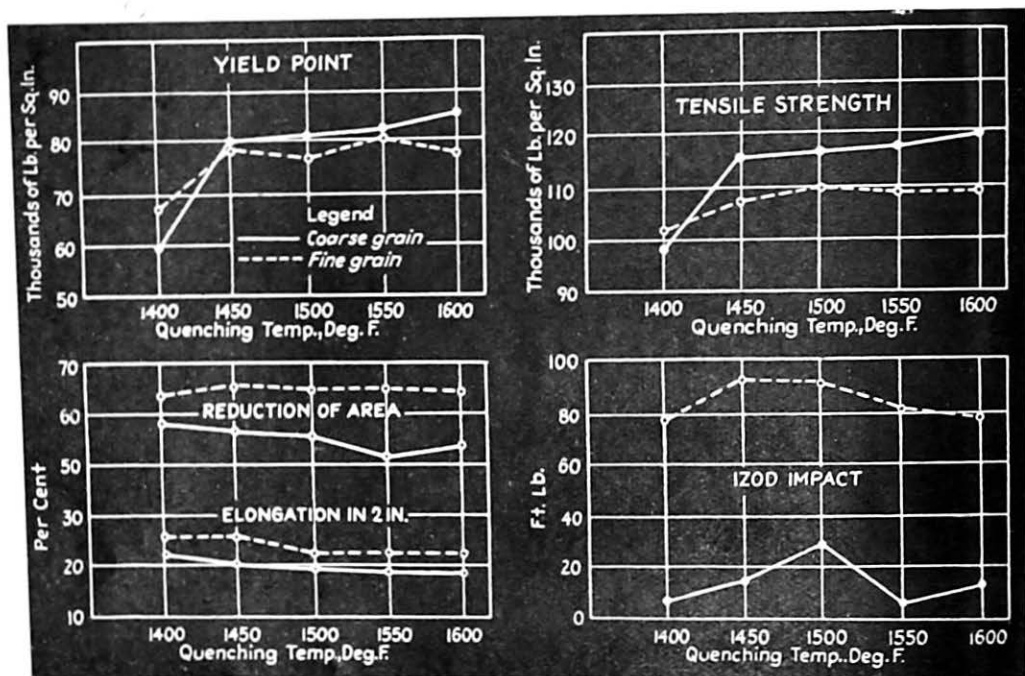


FIG. 4.—Graphs illustrating the differences in the Physical Properties of a Coarse and a Fine Grained S. A. E. 1040 Steel Quenched from the Temperatures Indicated and Tempered at 1050 deg. F. (Courtesy of P. Schane, Jr.)

O'Neill gave the following results for straight carbon steels in coarse and fine grain condition.

	A	B
Carbon ..	0.35%	0.35%
Silicon ..	0.22%	0.25%
Manganese ..	0.95%	0.96%
Sulphur ..	0.027%	0.027%
Phosphorus ..	0.036%	0.036%
Nickel ..	0.44%	0.46%
Chromium ..	0.06%	0.09%
Aluminium ..	0.001%	0.009%

Grain	Coarse	Finer
Yield stress tons per sq. inch	29.4	30.4
Max. stress tons per sq. inch	44.6	43.4
Elongation %	64	66
Izod value ft. lbs.	12	93

Fig. 4 shows a chart illustrating the relative physical properties of coarse and fine grained steels after quenching from various temperatures followed by tempering at 1050° F.

HARDENABILITY (Hardness & Penetration).

The properties of quenched steels are more directly related to their Austenitic grain size than those of annealed or normalized steels. It is necessary to differentiate between the potential maximum hardness attainable and hardenability or the depth of hardening of the mass of the metal. The maximum surface hardness attained on quenching does not greatly depend upon the Austenitic grain size for a given mass but the depth of hardening is influenced by the Austenitic grain size to a marked degree. This is illustrated in the following three diagrams, 5, 6 & 7.

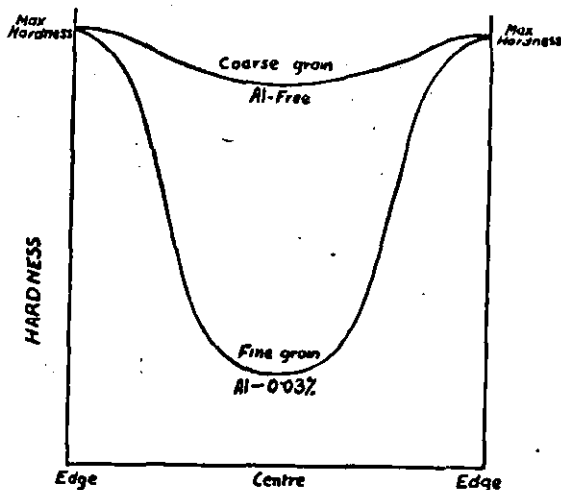


FIG. 5. Curves illustrating the variation of Hardenability with Grain Size.

The upper curve represents a deep hardening coarse grained steel and the lower curve a fine grained shallow hardening steel in which the hardness drops to a very low value in the Core. The surface hardness is the same in both the cases. Both the steel were quenched from the same temperature.

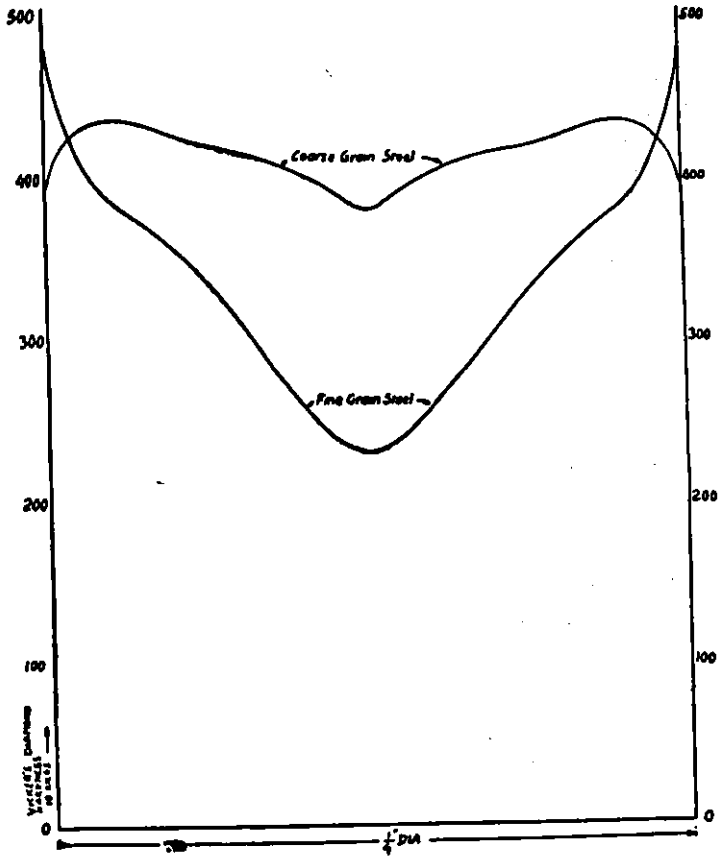


FIG. 6. Curves illustrating variation in Hardenability with Grain Size.

The curves shown above represents results obtained by the Author on two low carbon steels of identical composition, one of fine Austenitic grain size and the other coarse. The fine grained steel contained 0.02 % Aluminium while the coarse grained was Aluminium free. Both steels were quenched from 980° C. (Nijhawan).

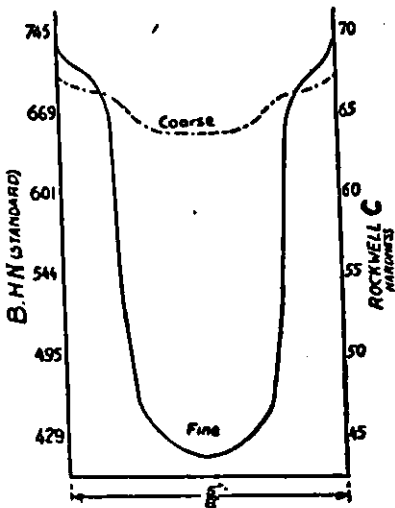


FIG. 7. Hardness Distribution across the $\frac{1}{2}$ inch thickness of two specimens of the same bar of Tool Steel.

One heated to 990° C., the other to 815° C., both quenched from a fixed temperature (Davenport and Bain).

Davenport and Bain heated two specimens of the same steel at 990°C. and 815°C. respectively. In the former a very coarse grain size was established and in the latter a fine grain size. Both specimens were cooled to 745°C. and quenched and the hardness at a series of fixed points determined across the section. Fig. No. 7 gives the hardness values across the section :

In general, the fine grained steels are shallow-hardening and the coarse grained types are deep-hardening and less subject to mass effect.

Due to larger Austenitic grain boundary surface areas in the case of fine grained steels, the transformation rates of these steels on quenching are faster than the coarse grained types. So in the case of the former the core undergoes comparatively rapid transformation and liberates more of the ferrite which makes it less hard and renders the steel shallow-hardening.

Since the toughness or impact values of hardened steels increase as the hardness diminishes, fine austenitic grained steels are not so hard in the core as coarse Austenitic grained steels. Therefore, they have tougher cores and resist dynamic stresses to a greater extent than similar deep hardening coarse Austenitic grained steels. Fine grained plain carbon steels can be economically substituted for low alloy steels where high core toughness is important. However, in tool and certain other types of steels where deep hardening properties are essential, the fine grained steel is unsuitable. Alloying elements like Manganese etc. add to the deep-hardening properties of the steel.

Fine grained steels are less liable to macroscopic cracking during quenching. Cases are on record where by making the steel inherently fine grained through suitable deoxidation, the rejections due to cracking in the heat-treatment were entirely eliminated. Fine-grained steels are also less liable to warping and distortion during heat-treatment. It has been further established that the micro-cracks observed in quenched steels result from large dimensional changes that increase with increasing grain size. Thus, the superior toughness of fine-grained steels is due to some extent at least, to the existence of a smaller number of microscopic cracks. Coarser grained steels have higher internal stress after quenching and are therefore, more susceptible to grinding cracks than the finer grained types.

However, due to their more rapid rates of transformation, finer grained steels are more prone to soft spots on quenching and are not suitable where full uniform hardening throughout the section is desired.

MACHINABILITY AND SURFACE FINISH AND FORGEABILITY AND PRESSING.

In America the view is widely held that coarse-grained steels machine better than fine grained. It is stated that in the coarse grained steels the size of the final ferrite and carbide lamellae resulting from the transformation of Austenite, is coarser and hence better machinability is imparted. However, completely identical results have not been obtained elsewhere. Where there is a great difference in the machinability as in the case of free-cutting and ordinary steels, it is easily shown but when the difference is small, it is difficult to discover which of the two types possess superior machining properties. However, the coarse grained structure causes roughness of the finished surface and the fine grained steels give a superior finish. In punch press operations fine grained steels exhibit several advantages over the coarse grained types. It has been shown that finished surface of fine grained mild sheets steels were much superior to those of coarse grained steels since the latter became rough after deep drawing whereas the fine grained steel remained smooth and uniform. In blanking,

fine grained types shear cleaner and exhibit smaller burrs and are less embrittled by cold work and therefore may be drawn deeper and show fewer defects than the coarse grained steels. Fine grained steels are more suitable for heavy punching operations, drastic cold rolling, shearing and trimming.

It is also reported that coarse grained steels forge more readily than fine grained types due to low interference to slip in the coarse grained types and that coarse-grained types give better fibre structures than the fine grained steels on forging.

CARBURIZING CHARACTERISTICS.

It has been observed that the rate of diffusion of carbon into fine grained Austenite is less rapid than in the coarse grained Austenite and so fine grained types carburize less deeply and more slowly than the coarse grained steels. Fine grained steel are prone to give abnormal or soft spots on quenching after carburization. 'Abnormal' spots refer to a coalesced state of carbide which causes low hardness values. The object of carburization is to obtain components with a case possessing a high surface hardness and of sufficient depth and a soft but tough core. The carbon content of a low carbon steel is usually raised by heating for a sufficient length of time in a carburizing atmosphere i.e., usually in a container packed with a solid carburizing compound. The carburized material is then quenched to harden the case. Apart from the shallow-hardening characteristics of fine grained steels these are ideal for carburizing. During the prolonged heating at the carburizing temperature, pronounced grain growth occurs in steels which have not been suitably deoxidized and are therefore coarse-grained. So after case-carburization, grain-refining treatments have to be carried out. The following is a complete cycle:—

- (a) Carburization and air cooling of the box after carburization.
- (b) Heating the material to just above the critical temperature range of the core, about 850°C-880°C. to refine its grain size, followed by quenching in oil or water.
- (c) Heating just above the critical temperature range of the high carbon case, about 750-770°C. to refine its grain size, followed by quenching in oil or water.
- (d) Final tempering at about 200°C. to relieve the internal stresses.

Where fine-grained steels are employed, the core and case retain their fine-grained characteristics after prolonged heating at the carburizing temperature and hence the core and case grain-refining operations etc. can be safely omitted and the case-carburized material quenched directly from the carburizing box. In some cases even the final tempering may also be dispensed with. It is now realized that so long as an allowance is made for the slower penetration of carbon in fine grained steels, these have pronounced advantages over the coarse-grained types in materially cutting down heat-treatment costs and time, yielding more production of an equally good if not, better case-hardened material. There is always the danger of warpage, distortion, macro-cracks in the heat-treatment cycle following carburization of the coarse-grained steels e.g., in case-hardened gear applications. Such dangers practically do not exist in fine-grained steels.

"Pipe"—*Shrinkage cavity*:—It is claimed that fine grained steels tend to give a deeper pipe than normal coarse-grained steels.

Decarburization:—It is reported by some investigators that coarse grained steels show a greater tendency towards de-carburization than the fine-grained types.

Aging :—It has been reported that fine-grained steels age much less than coarse-grained steels. The coarse grained steels show after aging an increase in the hardness, tensile strength, yield point and a greater loss in the impact toughness, reduction of area and elongation values than the fine-grained steels. In one case, the impact toughness of a fine-grained steel was actually shown to increase after aging. Embrittlement failures in boiler plate due to aging of strained areas about rivet holes, have been eliminated by the use of fine grained non-aging Izett steel.

Temper-Brittleness :—Temper-brittleness is the name applied to the loss of ductility or impact toughness that results after tempering hardened specimens to a temperature below the critical range followed by slow cooling. Steels containing alloying elements like nickel, chromium are chiefly susceptible to temper-brittleness. It has been shown by various workers that after tempering in the temper-brittleness range the Izod impact values of the fine grained steels are much greater than coarse-grained steels although the latter is somewhat less susceptible to temper-brittleness than the fine grain aggregates.

Magnetic Properties :—Ruder has correlated the existing data of the effect of grain size upon the magnetic properties of steels and has shown that the hysteresis, coercive force and residual all decrease with increase in grain size. This condition varies with prior treatments whether mechanical or chemical and consequently the effect of grain size cannot readily be ascertained.

Grain size control and its practical applications :— A full understanding of the characteristics of fine and coarse grained steels has led to the choice of each type for different purposes. Coarse grained steels are recommended for easy machinability, deep hardening etc. and fine-grained steels are preferred for advantages hitherto obtained from alloying elements e.g., greater toughness with a given strength and hardness, wide heat-treating range, freedom from danger of cracking, warpage etc., and the elimination of grain-refining treatments after carburizing. All these attributes should be taken into consideration for the purpose of selection of the steel for a particular purpose. Where machinability is of prime importance, fine-grained steels with their attendant higher toughness etc., can also be usefully employed after normalizing from a high temperature to improve their machining. Where deep hardening properties are of paramount importance, fine-grained steels could also be employed with an increased manganese content and their slightly lower strength improved by tempering at a lower temperature. A balanced view of the whole range of the characteristics of the two types has established that for all uses of steels involving heat-treatment, fine grained materials with suitable alterations of heat-treatment and composition, are of a actually better quality than coarse grained types. Fine-grained steels can be economically substituted for low alloy coarse grained types and fine grained low alloy steels substituted for high alloy coarse grained types. For example, in case-carburized or hardened gear applications, low alloy coarse grained steels can be replaced by fine grain un-alloyed steels which, because of their shallow hardening characteristics give an equally hard case and a tougher core with complete freedom from dangers of distortion and cracking during hardening following carburization or hardening as such. This control of distortion is important in order to avoid heavy localized tooth pressure by irregular and small tooth contacts. Besides, the grain-refining operations following carburization can be safely omitted with attendant economy and an increased production of a sounder, crack-free, case-hardened product. In particular cases, even carburization itself may be eliminated since fine-grained shallow hardening steels on hardening will give an outer shell of fully hardened steel produced on a softer but tougher core of the same composition.

Swinden and Bolsover state that they are in favour of inserting a grain size specification clause for engineering materials which will ensure a more regulated product and will serve as an alternative, within limits to the addition of increased contents of alloying elements which may be comparatively expensive and which almost certainly add to the difficulties of manipulation and heat-treatment of the alloyed materials as well as, in some cases, causing complications connected with such operation as flame-cutting and welding. Flame-cutting and welding of coarse-grained alloy or carbon steel cause excessive and deep hardening of the metal with possibility of cracking therein. Without making exaggerated claims for the fine grained steels it can be stated that if and when the Engineer desires better impact toughness with a given tensile strength or a high tensile strength with a given impact resistance it will be worthwhile for him to study the possibility of achieving his objective by the use of controlled-grain size steel as a substitute for a low or highly alloyed steels.

Hugh O'Neill in his excellent paper on "Alloy and Fine grained steels for locomotive complying rods" (J.I.S.I. 1937 No. 1) gives details of plain carbon steels of inherent fine grain which yield practically the same mechanical properties as low alloy steels and are giving satisfactory performance both during manufacture and in service as coupling rods for the L.M.S. Railway.

William (J.I.S.I. 1938 II) while referring to American steel industry estimated that 75 % of all killed steel made in the United States is made under specifications requiring grain size control. In general, it is now possible to produce steels of coarse or fine grain at will, by the omission or regulated additions of aluminium to steel of just the proper degree of deoxidation. Intermediate sizes cannot be so precisely controlled yet but progress is being made through the use of vanadium, titanium and zirconium separately and in various combination along with aluminium.

With India on the threshold of big post-war industrial development in the field of Metallurgy, it will be a wise and far-sighted attitude on the part of Indian steel-makers as well as the users like the Railways, to study the application of grain size control to their requirements of various types of Indian steels which have hitherto been made or will have to be produced in the not too distant a future in this country and which will in the long run feed the heavy Indian Engineering Industries such as the manufacture of locomotives, automobiles and the rest.

METHODS OF DETERMINING AUSTENITIC GRAIN SIZE A. McQUAID-EHN CARBURIZING TEST.

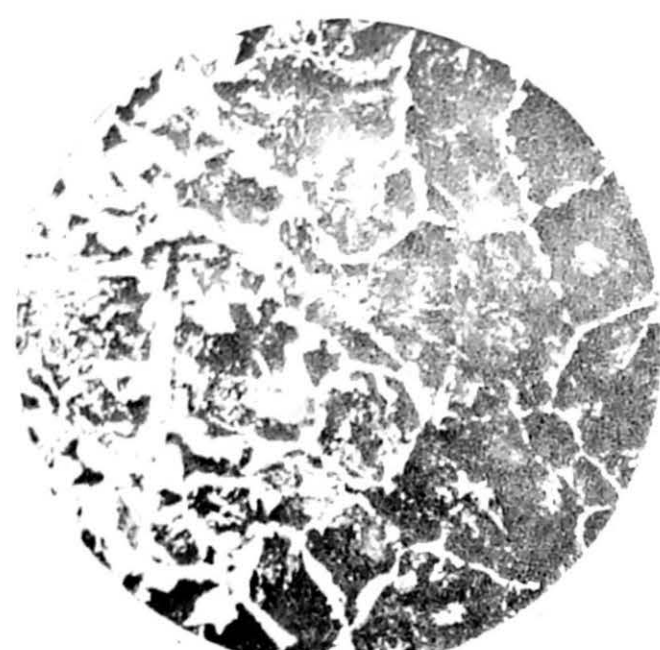
This is based on the work of original American investigators and issued as the A.S.T.M. Standard E. 19-33.

A specimen is selected of a suitable size to obtain a convenient Micro-section when parted into two. All scale is removed from the specimen and it is packed in a box containing a good carburizing compound. The box is carefully sealed to prevent the escape of carburizing gases. The box and contents are heated in 2 hours and soaked for 6 hours at 927°C. and then allowed to cool slowly down to 400°C. before emptying. A section is cut from the sample, polished on the cut face and etched. The free carbide of the carburized case outlines a clearly defined grain size which is examined on a projection microscope at a magnification of 100 diameters. Comparison of the projected fields with those given on the standard charts in Fig. 8 which shows typical standard fields for each grain size, enables the inherent Austenitic grain size of the specimens

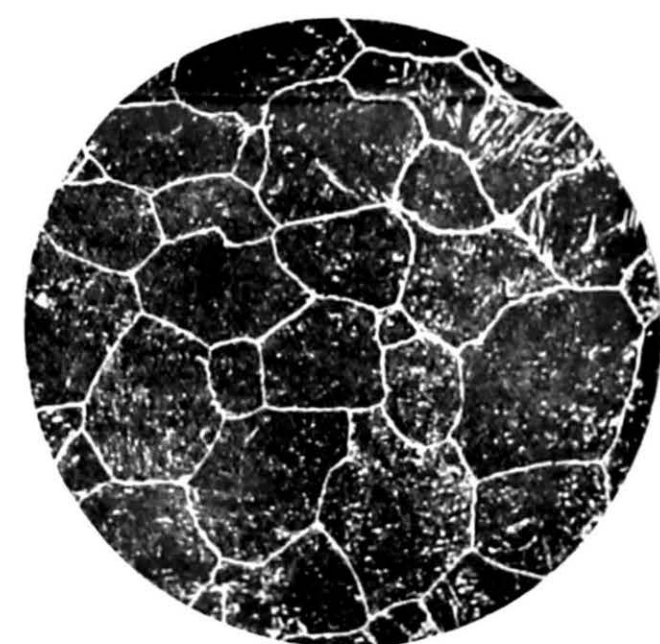
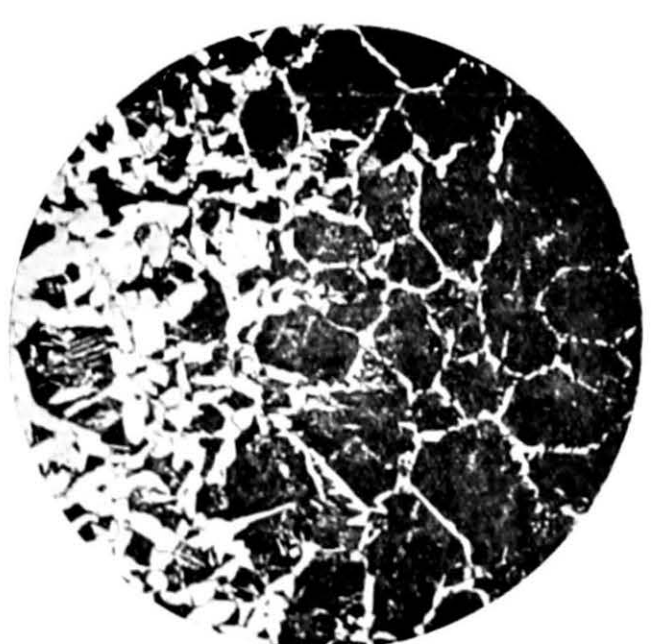
FIG. 8—GRAIN SIZE CHART FOR CLASSIFICATION OF STEELS (A.S.T.M. STANDARDS)
 Samples carburized at 1700°F. (927°C.) for 8 hours (X 100)

Hypo-Eutectoid

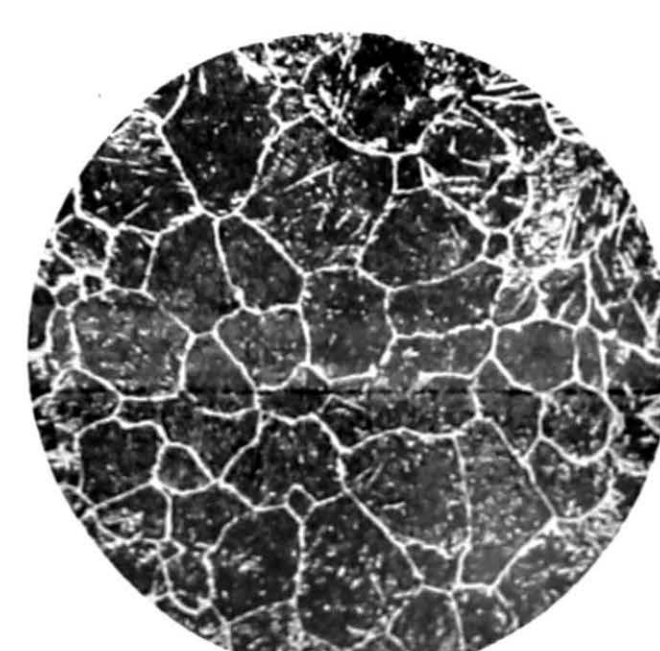
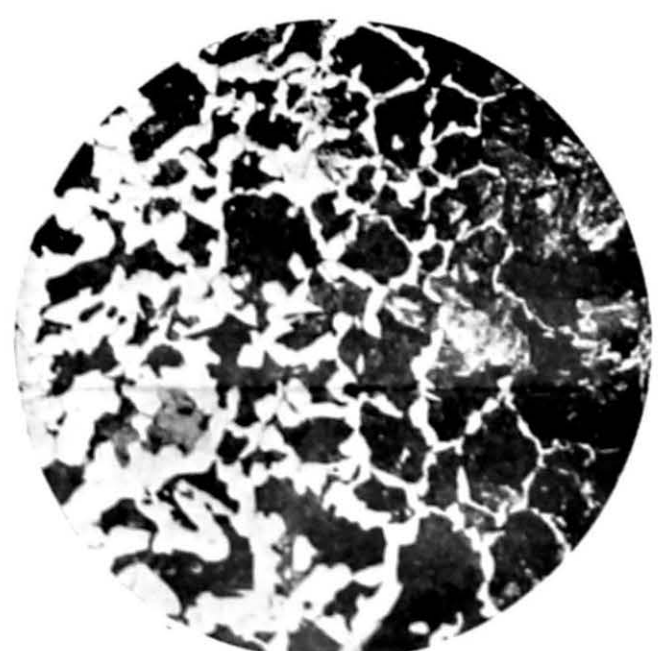
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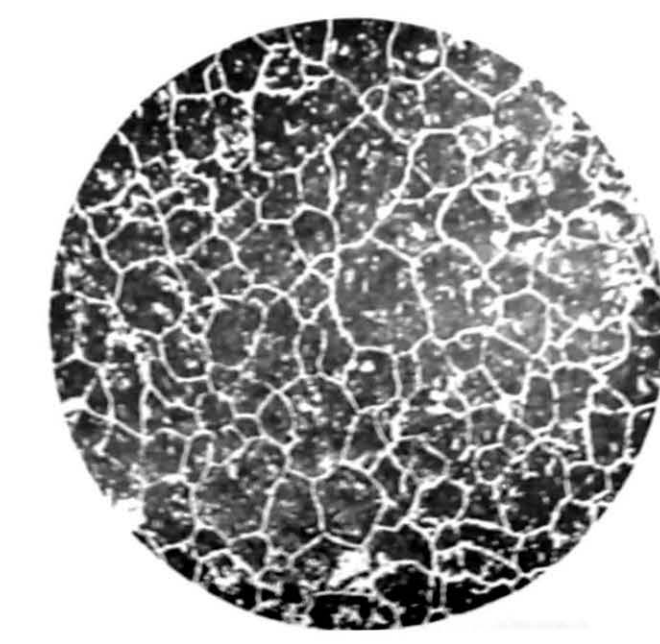
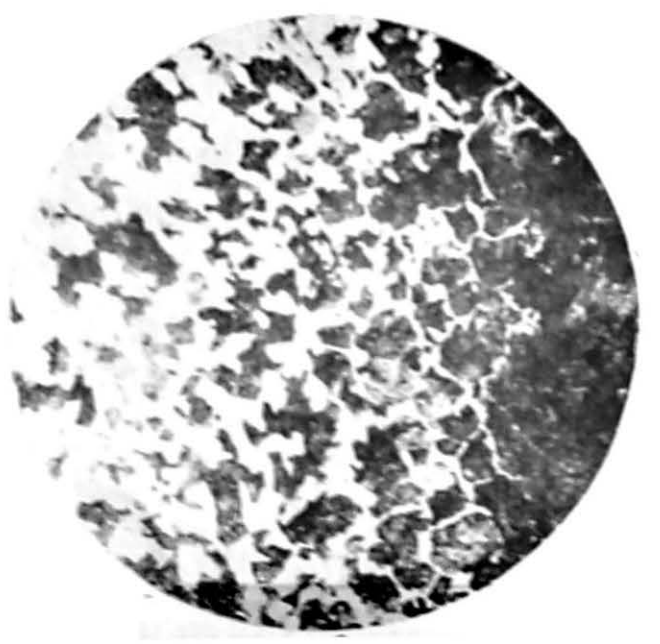
No. 1. Up to 1-1/2 grains per sq. inch.



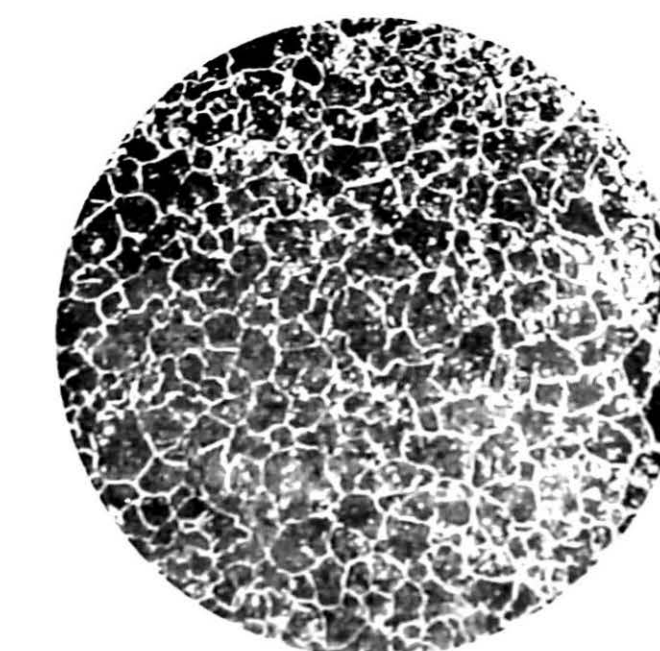
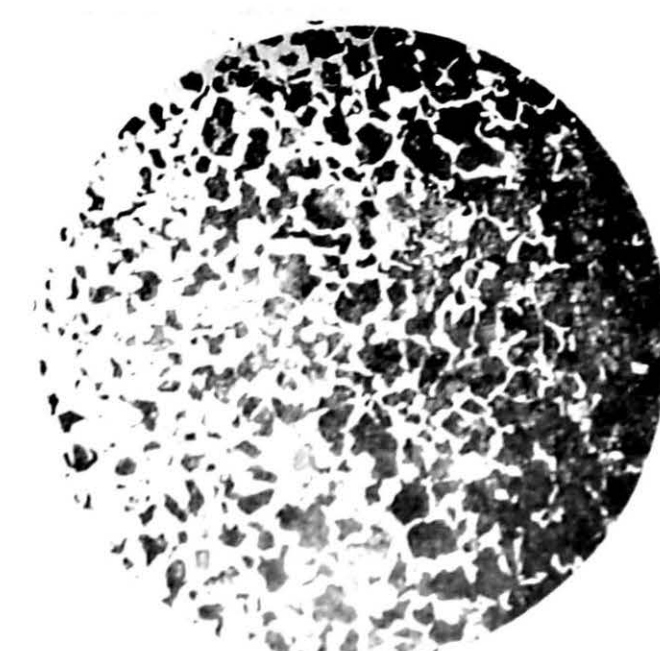
No. 2. 1-1/2 to 3 grains per sq. inch.



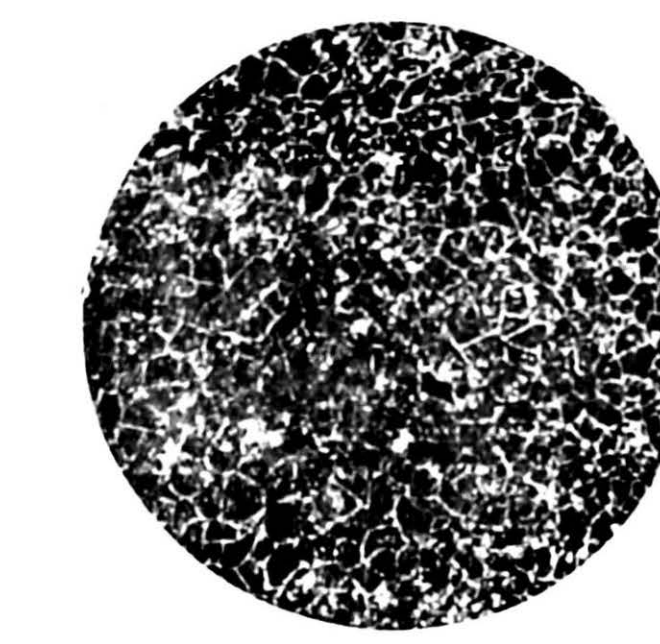
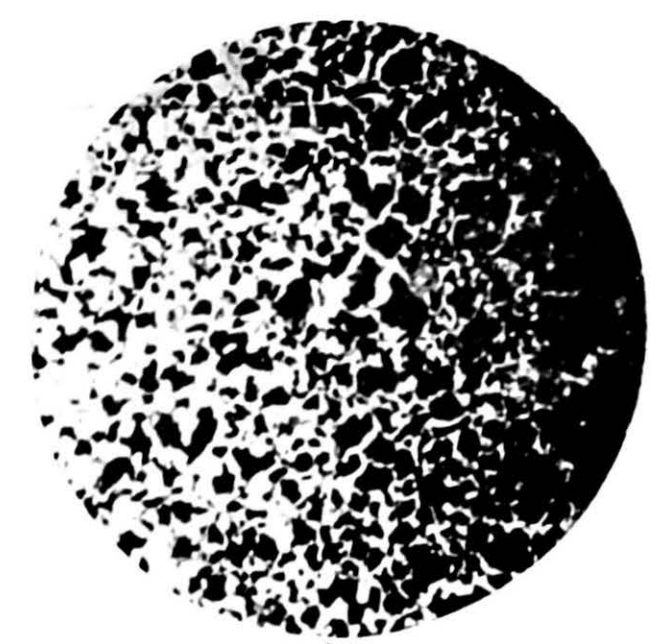
No. 3. 3 to 6 grains per sq. inch.



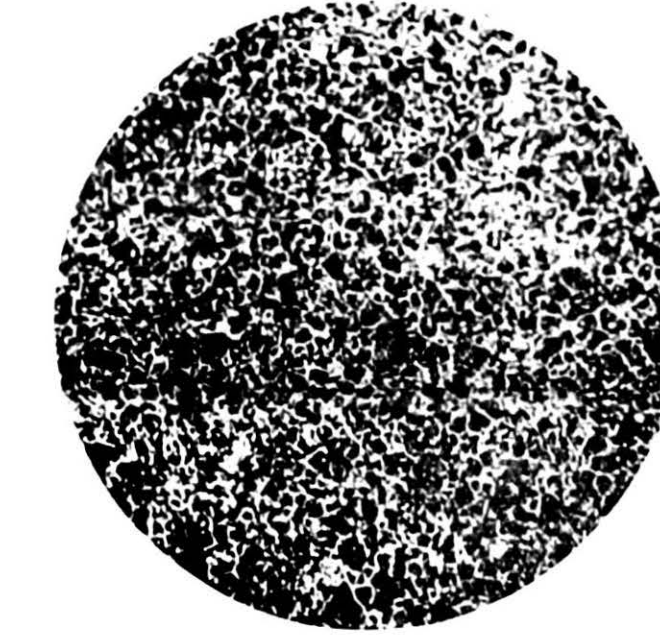
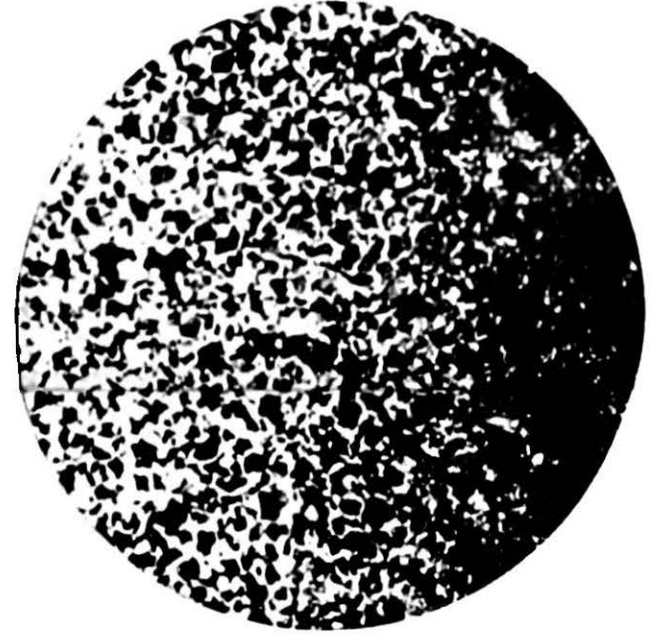
No. 4. 6 to 12 grains per sq. inch.



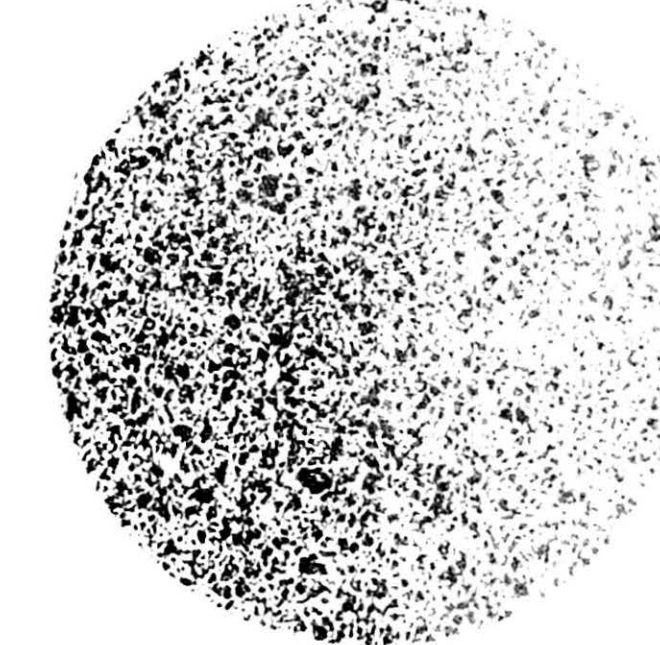
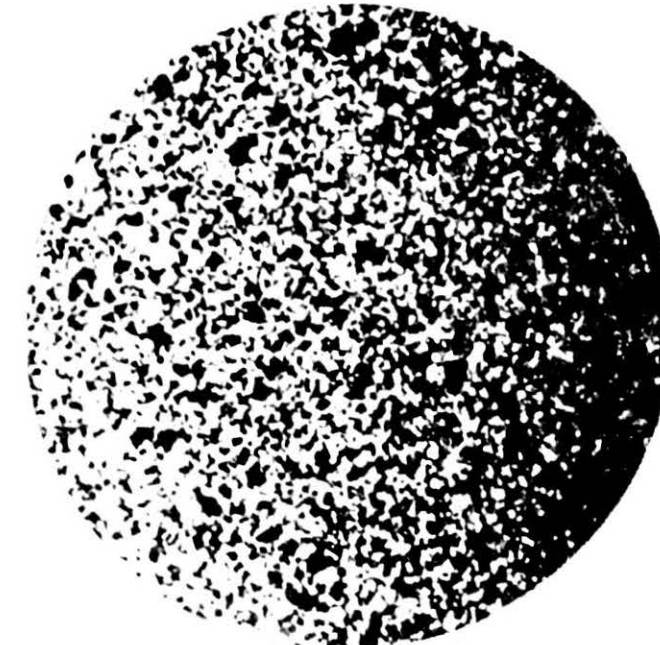
No. 5. 12 to 24 grains per sq. inch.



No. 6. 24 to 48 grains per sq. inch.



No. 7. 48 to 96 grains per sq. inch.



No. 8. 96 grains and more per sq. inch.

to be assessed. It is an arbitrary method of determining the size of the Austenite grains which had formed at a specified carburizing temperature, i.e., 927°C. The grain size is reported as a number which, in fact, represents the numbers of grain per sq. inch at a magnification of 100 diameter. The following tabulation illustrates the basis of the 8 Standard grain sizes normally worked to—

Grain size index. N	Number of grains per sq. inch × 100, n		
	Mean	Maximum	Minimum
1	1	1.5	..
2	2	3	1.5
3	4	6	3
4	8	12	6
5	16	24	12
6	32	48	24
7	64	96	48
8	128	..	96

As the basis of this table is $n = 2^{N-1}$, the index for smaller or larger grain size may be calculated. Most coarse grained carbon steels have the index 2 or 3 and most fine grained have 6 or 7. In alloy steels, the grain sizes are smaller and when the content of alloying elements is substantial, the effect of strong deoxidation etc., on the grain size and its accompanying characteristics tends to become negligible. The Mcquaid-Ehn test has become the standard method of determining Austenitic grain size and is one of the major routine tests employed by user and producers in America. All the characteristics of the fine grained steels can be related to the Mcquaid-Ehn-grain size.

Fig. 9 shows the standard Austenitic grain size chart for steels prepared by Messrs. Timken Roller Bearing Co. of America.

There are some other methods of ascertaining the Austenitic grain size and are outlined as follows:—

Oxidation method:—Suitable marking of the Austenitic grain boundaries can be obtained by heating a polished surface of a specimen in an electric furnace at a standard temperature. The specimen is then taken out and air cooled. The oxide scale is removed and the specimen repolished and etched. The former Austenite grains are outlined by the absorption of oxygen at the Austenitic grain boundaries.

Another method developed by O'Neill flash-etches the Austenitic grain boundaries at the surface of steel specimens at high temperature by dry chlorine. The specimen is then cooled, suitably etched and examined.

In carbon steels of about 0.7-0.9% carbon content, the steel is simply quenched from above the critical temperature range and the former Austenite grain size revealed by etching with "Vilella & Bain" etching reagent preferably after tempering the specimen at 200° C-300° C.

In low and medium carbon steels a simple method is to take a steel test-piece, heat to above the critical temperature range, water-quench one of its end whilst leaving the other end to air cool. The test piece is then longitudinally cross-sectioned and micro-examined. The former Austenitic grains are in one area in the section outlined by a dark, partially transformed product of Austenite, termed Troostite, around Martensitic matrix—another transition product obtained during the transformation of Austenite.

THE SHEPHERD-PENETRATION-FRACTURE TEST FOR TOOL STEELS.

The Shepherd-penetration-fracture or simply P-F test consists essentially in subjecting four samples of tool steels in question to brine quench at temperatures of 1450°F., 1500°F., 1550°F. and 1600°F. respectively. Each specimen is then notched and broken, and from a comparison of one of the fractures with a set of standard fractures, the fracture-grain-size is determined. The penetration is determined by macro-etching the other half. From a correlation of these data, the P-F values are determined.

Results :—The Metallurgical Laboratory of this Inspectorate has been conducting from time to time Mcquaid-Ehn carburizing Austenitic grain-size tests in the course of its investigations on various types of steels including failed Railway materials, both of Indian and non-Indian manufacture. It is not possible to give here all the results of such grain-size determinations. However, micro-photographs Nos. 10 to 21 illustrate the Mcquaid-Ehn Austenitic grain sizes revealed in the course of such investigations. The necessary details are given.

It is a policy of this Inspectorate to pursue further investigations on "Controlled Grain Size" particularly on Indian steels in their application to Engineering and Railway materials and other allied steel industries.

Comments on the results :—Tyre steels represented by Figures 13, 14 and 15 of fine grained quality gave Izod values of 11 ft. lbs. against the values of 4 ft. lbs. given by the coarse grained tyre steels shown in Figures 10, 11 and 12. The former contained Carbon 0.58%, Manganese 0.62%, Sulphur and Phosphorus each below 0.04% and the latter contained Carbon 0.59%, Manganese 0.58%, Sulphur and Phosphorus each below 0.04% i.e. both possessed identical composition.

Duplexed Austenitic grain structures have also been observed by Lauderdale and Harder on case-carburized S.A.E. steels and is believed to be due to excessive rate of growth of some individual grains following certain conditions of deoxidation of the steel.

ACKNOWLEDGEMENTS.

No claim for originality is intended in this short review. It is merely an outline of the data on the subject to which are appended just the minimum of the experimental results obtained here, designed to introduce the subject to the Engineers.

The author desires to acknowledge gratefully the invaluable advice and encouragement which he has received from Mr. R. C. Arbery, O.B.E., Controller of Inspection (Metallurgical), Department of Industries and Supplies. The author also wishes to thank Mr. T. V. N. Kidao, Assistant Inspecting Officer, Department of Industries and Supplies for assistance.

PHOTO MICROGRAPHS SHOWING AUSTENITIC GRAIN SIZE IN STEELS.



FIG. 10. Coarse grained tyre steel etched
in Sodium Picrate.
X 100



FIG. 11. Extremely coarse grained tyre steel
etched in Nital.
X 100

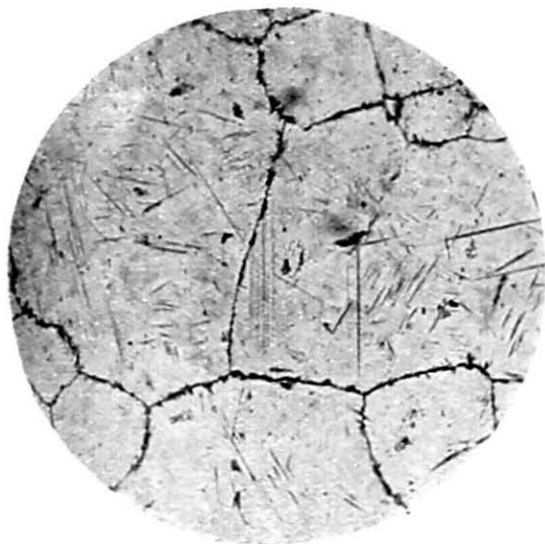


FIG. 12. Coarse grained tyre steel etched
in Sodium Picrate.
X 100

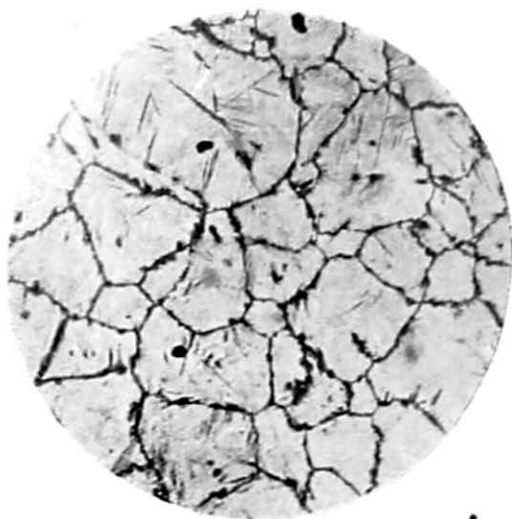


FIG. 13. Fine grained tyre steel etched in
Sodium Picrate.
X 100

PHOTO MICROGRAPHS SHOWING AUSTENITIC GRAIN SIZE IN STEELS.

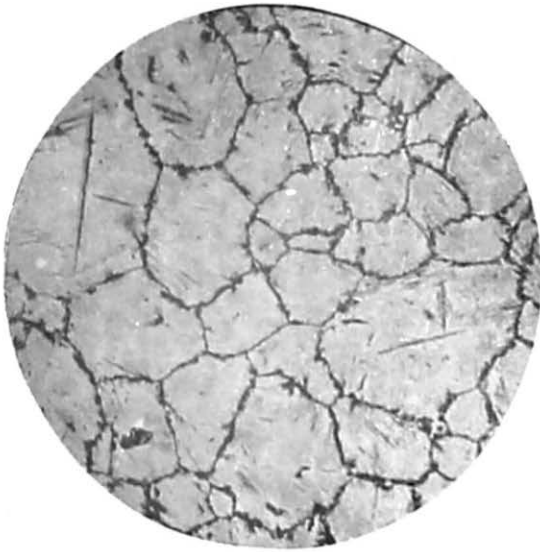


FIG. 14. Fine grained tyre steel etched in Sodium Picrate.
X 100

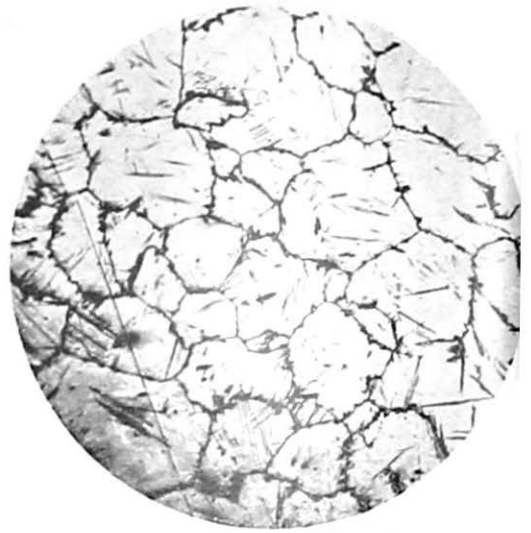


FIG. 15. Fine grained tyre steel etched Sodium Picrate.
X 100

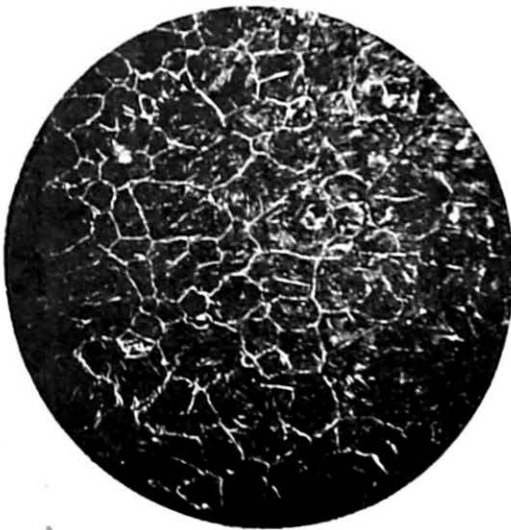


FIG. 16. Fine grained tyre steel etched in Nital.
X 100

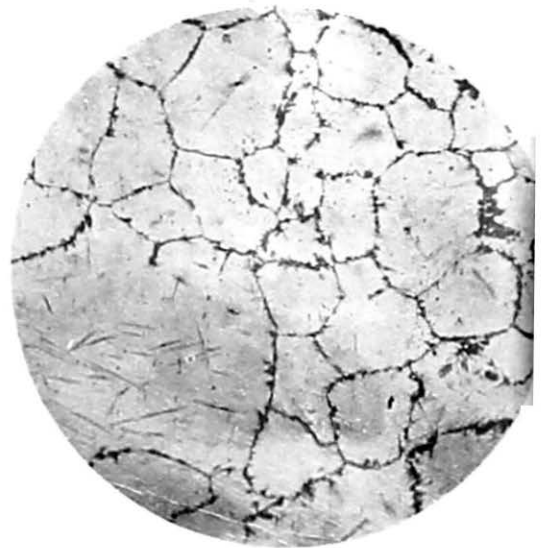


FIG. 17. Duplexed grained tyre steel etched in Sodium Picrate.
X 100

PHOTO MICROGRAPHS SHOWING AUSTENITIC GRAIN SIZE IN STEELS.

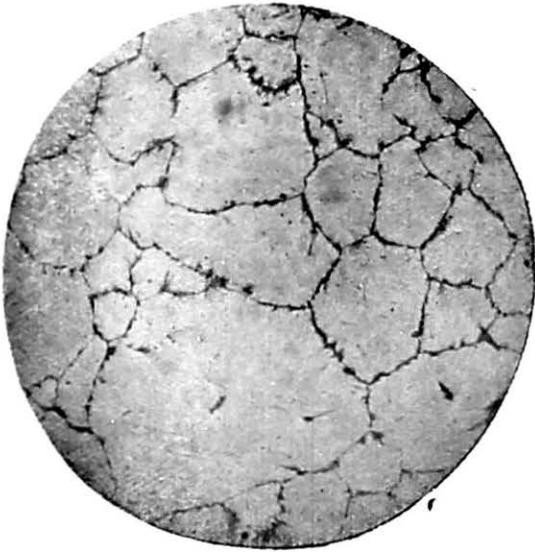


Fig. 18. Tyre steel showing Duplexed grained structure etched in Sodium Picrate.

X 100

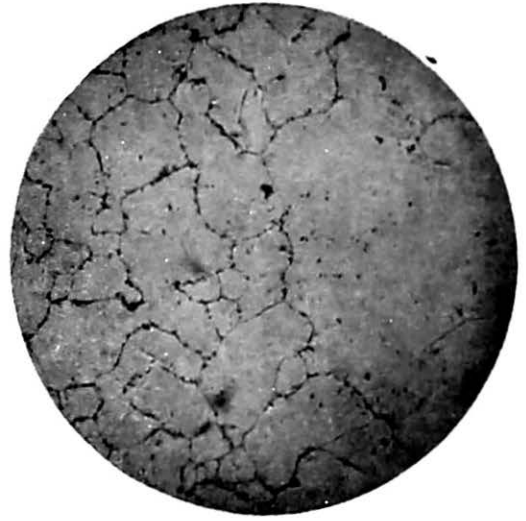


Fig. 19. Axle steel showing Duplexed grained structure etched in Sodium Picrate.

X 100



Fig. 20. Fine grained Axle steel etched in Sodium Picrate.

X 100



Fig. 21. Coarse grained Axle steel etched in Sodium Picrate.

X-100

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