

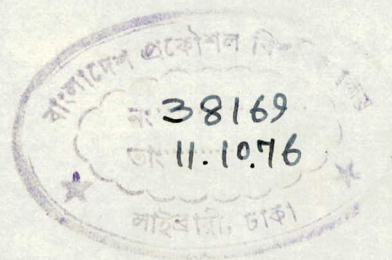
STUDY ON THE POSSIBILITY OF USING TITAS GAS AS A CARBURIZING MEDIUM FOR SURFACE HARDENING OF LOW CARBON STEEL

By

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B. Sc. Engg. (Met.)

A thesis submitted to the Department of Metallurgical Engineering, BUET, Dacca in partial fulfilment of the requirements for the Degree of Master of Science in Engineering (Metallurgical).



Bangladesh University of Engg. & Tech.,
Dacca.



#38169#

August, 1976.

CERTIFICATE

This is to certify that this research work was done by the author under the supervision of Dr. M. Ibrahim, Professor and Head, Department of Metallurgical Engineering, Bangladesh University of Engineering and Technology, Dacca and it has not been submitted anywhere for the award of any degree or diploma or for publication.

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Signature of the supervisor

Md. Mohar Ali Bepari

Signature of the author



The undersigned examiners appointed by the Committee of Advanced Studies and Research (CASR) hereby recommend the acceptance of the thesis "STUDY ON THE POSSIBILITY OF USING TITAS GAS AS A CARBURIZING MEDIUM FOR SURFACE HARDENING OF LOW CARBON STEEL" submitted by Mr. Md. Mohar Ali Bepari, B.Sc.Engg. (Met.) to the Department of Metallurgical Engineering, BUET, Dacca in partial fulfillment of the requirements for the Degree of Master of Science in Engineering (Metallurgical).

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ABSTRACT

Low carbon steel is carburized by heating in a mixture of hardwood charcoal, sized coke, barium carbonate, calcium carbonate etc. The temperature employed for heating the carburizing mixture is about 900°C . Sometimes procurement of these chemicals become a problem. Some of these chemicals are imported materials for Bangladesh. This project was undertaken to study whether locally available natural gas supplied by the Titas Gas Transmission and Distribution Company, Ltd. can suitably be utilized in carburizing the low carbon mild steel. A small experimental furnace has been built and low carbon mild steel specimens of about 0.20 percent carbon were heated in a cast iron cylinder containing Titas Gas to a variable time and temperature range. It has been found that low carbon mild steel gets carburized easily and the depth of carburization is found to be a function of time and temperature i.e. higher the temperature, deeper is the case depth and also longer is the period of carburization, more is the penetration of carbon into steel.

To make a comparative study for the speed of carburization among Titas Gas, pure carbon and conventional carburizing mixture, some experiments were conducted with a mild steel shaft of about 0.22 percent carbon. It was found that carburization is quicker by Titas Gas compared to that of carburizing mixture and pure carbon.

Some experiments were also done along with carburizing mixture and solid carbon, in a variable pressure. It was also revealed that higher the pressure more is the depth of carburization.

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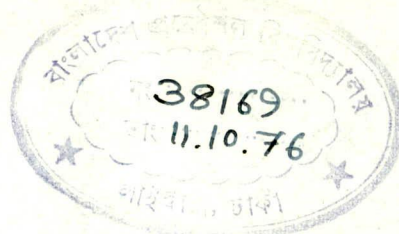
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CHAPTER - I

INTRODUCTION





INTRODUCTION

The service conditions of many machine parts made of steel demand very hard and wear-resistant surface but with tough and shock-resistant core. Such a combination of properties is not usually possible from the commercial steels. A low carbon steel containing carbon 0.30 to 0.35 per-cent is sufficiently tough while a high carbon steel containing carbon upto 1.00 percent possesses adequate hardness. By suitable heat-treatment the high carbon steel can be made very hard while the low carbon steel will develop sufficient toughness. A machine part requiring hard surface but tough core will require a combination of high carbon at the surface and low carbon for the core which on heat-treatment will develop very hard surface and tough core.

To develop a steel of high carbon at the surface and low carbon at the core has become a problem to the manufacturer of machine parts till the knowledge of carburization was discovered by an earlier black smith¹ who, while working in his forging shop, observed that wrought iron when heated on the bed of glowing charcoal picked up carbon and became high carbon steel. This carburized steel when quenched from red hot condition became very hard on the surface. This knowledge made the modern metallurgist to develop several processes of surface hardening of low carbon steel which may be summerised as follows:

1. Carburizing
2. Cyaniding and
3. Nitriding.

The surface hardness obtained by the first two processes (carburizing

and cyaniding) depends upon heat-treatment after the appropriate composition of the case has been attained. The third process (nitriding) alters the composition of the case in such a way that the compounds formed are inherently hard and does not require any heat-treatment.

Carburizing is the most satisfactory and widely used method of surface hardening of low carbon steel. It is a process by which the carbon content of the surface of a steel is increased. Since the object of surface hardening is to obtain a hard, wear-resistant surface with a tough interior, the first consideration is the selection of a low carbon (usually 0.20 percent carbon) steel. It is then subjected to carburization to an extent of eutectoid-hyper eutectoid composition and by subsequent heat-treatment to the desired hardness.

There are three general methods of carburization, each differing in technique; they are as follows:

1. Solid or pack carburization
2. Liquid carburization
3. Gas carburization

The choice of the method to be followed depends upon the type of case wanted.

In pack carburization process, parts to be carburized, are charged in a heat-resisting metallic box with carburizing mixture. The carburizing mixture is of the following proportions²:

Hardwood charcoal	53 to 55 parts
Sized coke	30 to 32 parts

Barium carbonate	10 to 12 parts
Calcium carbonate	3 to 4 parts
Sodium carbonate	2 to 3 parts.

The depth of carburization depends on time, temperature and the type of mixture used. For example, with a typical carburizing mixture of the above proportions, a case depth of 0.04 to 0.05 inch can be obtained at 925°C in an over-all carburizing time of nine hours including about five hours heating and four hours holding at the constant temperature². The pack carburization is economical and advantageous for small machine parts; but it has limitations in handling larger and complicated parts and also has some limitations in heat-treatment.

The liquid carburization is used for parts requiring thin carburized cases. The complicated machine parts are also carburized by dipping them in the liquid bath. The carburizing liquid bath is a cyanide solution from where carbon is diffused from the bath to the machine parts. The peculiarity of this process that the temperature of the bath is to be maintained slightly above the AC_1 line - about temperature 800°C. This process has the disadvantages that the material as well as the fumes coming up from the bath is poisonous.

The practice of carburization by methane as well as cracked gas is the latest development. Natural gas containing methane, ethane, etc. may also be used as a carburizing medium. But a definite proportion of gases helps in the rapidity of carburization. No literature is found whether any attempt has been made to use Titas Gas as a carburizing medium. This project "STUDY ON THE POSSIBILITY OF USING TITAS GAS AS A CARBURIZING MEDIUM FOR SURFACE HARDENING OF LOW CARBON STEEL" has been under taken in order to explore large

scale application of Titas Gas for carburization.

The chemical composition (by volume) of Titas Gas³ found in Brahmanbaria in the district of Comilla is as follows:

Methane (CH_4)	97.2 percent
Ethane (C_2H_6)	1.8 "
Propane (C_3H_8)	0.5 "
Butane (C_4H_{10}) &	0.2 "
Higher hydrocarbon	
Nitrogen (N_2)	0.3 "

Its calorific value is about 1039 Btu/cft.

Pack carburization now in practice requires different types of chemicals such as barium carbonate, activated charcoal, sized hard coke, sodium carbonate etc. Since some of the chemicals are imported and are not available in the local market, pack carburization sometimes becomes a hard proposition to follow. Moreover the box containing the charge when heated gets oxidized and warrant frequent replacement.

If it can be established that carburizing or case hardening is possible by Titas Gas, then pack carburization by conventional method can be replaced by locally available Titas Gas and thus botheration in procuring different ingredients will be eliminated. The process developed in this project may be applied in commercial scale in industries in Bangladesh.

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CHAPTER - II

THEORY OF CARBURIZATION

THEORY OF CARBURIZATION

The carburization of steel may be explained on the basis of two fundamental concepts. The first is diffusion, influenced by the properties of the iron, and concerned with the movement of carbon in the iron itself; the second deals with the source supplying the carbon, and with the transfer of carbon to the surface.

These two general concepts may be described briefly:

1. Fick's Law⁴ of diffusion is

$$\frac{dm}{dt} = -SD \frac{dc}{dx}$$

where $\frac{dm}{dt}$ may be taken as the time rate of flow of the solute, carbon, through the area S . This rate is proportional to the area itself, where D is the proportionality factor or diffusion coefficient. The rate is also proportional to another factor, $\frac{dc}{dx}$, which expresses the rate at which the carbon concentration c varies with the depth x . The flow of carbon in gamma iron is in part analogous to the flow of heat in solids, and to some extent expressions developed for the conduction of heat are applicable.

2. The equilibrium state⁴ for chemical reactions may be represented by numerical constants, K_p , derived from the general expression

$$\text{Log } K_p = \frac{A}{T} - B$$

where K_p is a numerical factor termed the "equilibrium constant", which is derived from the values for the concentrations of the reactants and products of a chemical reaction. The subscript p denotes the dependency of the chemical reaction on pressure. T is the absolute temperature at which the reaction

takes place. A and B are constants derived for the particular reaction.

Instead of being developed in a formal way from the basic principles, the mechanism of carburization may be analyzed from the view point of carbon flow, by stating the controlling factors⁴. These factors may be divided for discussion into two distinct classifications:

- 1) factors that control the flow of carbon in iron
- 2) factors that influence the transfer of carbon to the iron surface.

The mechanism may be explained as follows:

The flow of carbon in iron: Iron when heated in presence of carbon makes solid solution. A solid solution may be described to be a solution of two or more components as solute and solvent sharing their atoms in their initial cells in the solid state. In other words a solution may be defined as any phase of which the composition may vary continuously within certain limits. Carburizing is concerned with the solid solution of carbon in austenite. The limits of carbon content of this phase depend on the temperature and the composition of the steel. The solid solution of carbon in gamma iron is an interstitial type of solid solution. As is evident from the iron and iron-carbide thermal equilibrium diagram Fig. 1, at temperature below about 1670°F , pure iron occurs as a body centered cubic structure. Above 1670°F there is a temperature range in which iron has a face centered cubic structure. In face centered cubic lattice, a relatively large unoccupied "hole" exists in the center of the unit cell⁵. Carbon being an extremely small atom can move into this hole to produce a solid solution of iron and carbon as shown in Fig. 2. When iron has a body-centered cubic structure at lower temperatures, the interstices between the iron atoms become much smaller and consequently

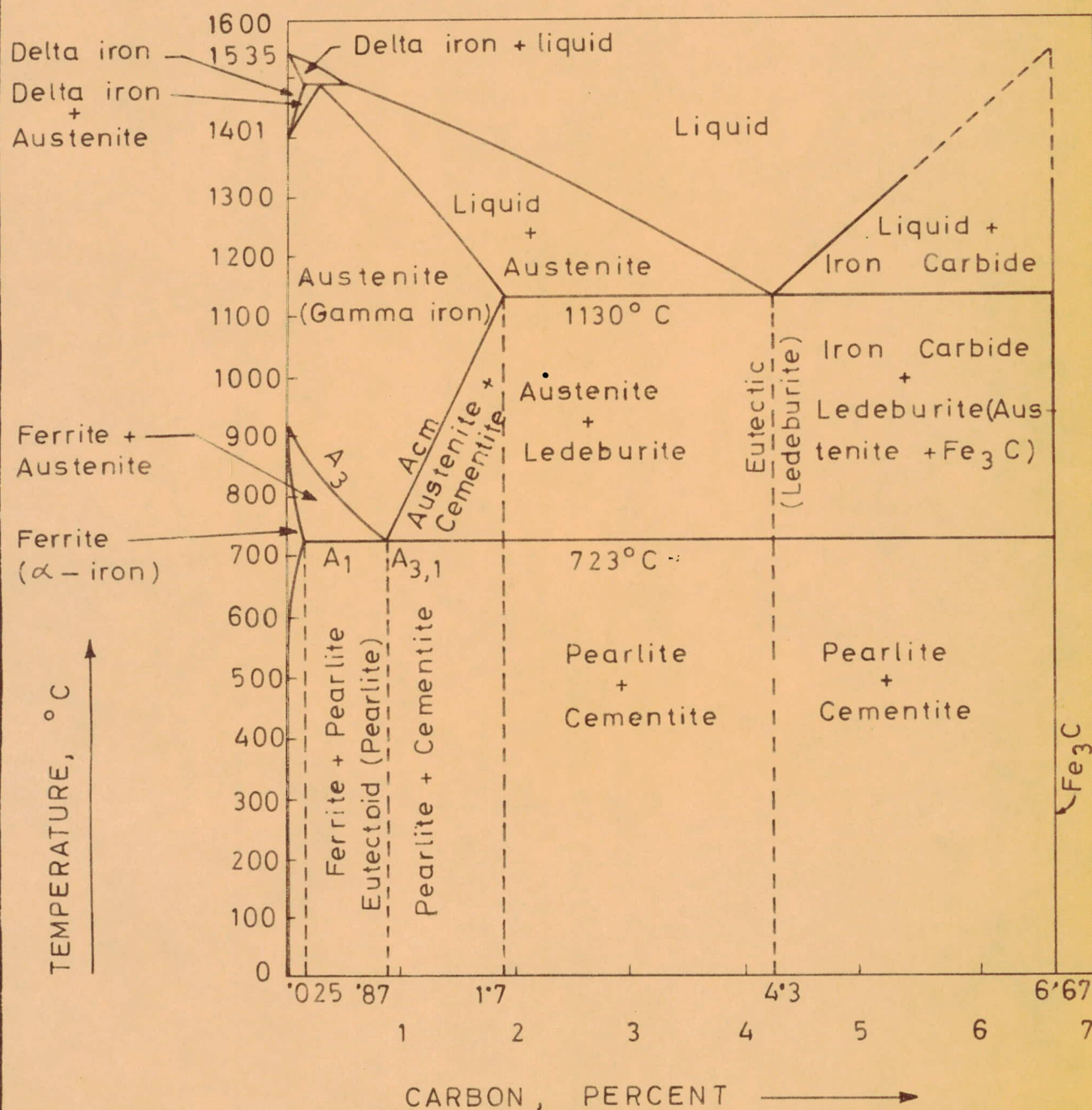


FIG. 1 IRON AND IRON-CARBIDE EQUILIBRIUM DIAGRAM.

the solubility of carbon in body-centered cubic iron is relatively small.

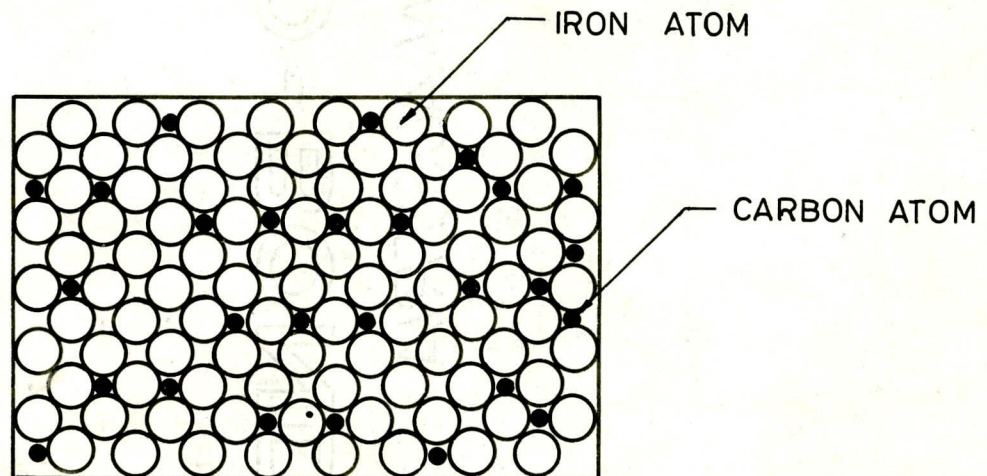


Fig.2 Interstitial solid solution (carbon in fcc iron).
 (Clyde Mason, Introductory Physical Metallurgy.
 Cleveland: American Society for Metals, 1947.)

The penetration of carbon into the iron forming steel will depend upon the temperature, the time at temperature, and the carburizing agent. Since the solubility of carbon in steel is greatest above the A_{c3} temperature, carburization takes place most readily above this temperature. Furthermore, the higher the temperature, the greater the rate of carbon penetration, since the rate of diffusion is greater. It is customary to select a temperature about 100°F above the A_{c3} point. The carburizing temperature is an important factor and is usually maintained within 900°C to 925°C . The depth of carbon penetration depends mostly upon the holding time.

Fig. 3(a) shows the carburizing procedure in which a low-carbon iron (carbon-free iron) is held for several hours at a high temperature in contact with an atmosphere, such as natural gas, capable of supplying carbon to the metal. The initial carbon content of the iron plate is zero at all distances from the surfaces. As the carbon atoms go into solution at the surface of iron, they are free to begin diffusing further into the plate. The maximum concentration of carbon atoms in iron at 1700°F can be used from the iron-carbon diagram, and is about 1.3% carbon⁶. The carburizing atmosphere can build up this carbon concentration at the surface almost immediately, so that the carbon penetration curve shortly after the beginning of carburizing is of the form shown in Fig. 3(b). The carbon penetration curve that is produced by carburizing for a number of hours at a given temperature (1700°F in this case) is shown in Fig. 3(c).

The rate of flow of carbon in austinite depends on values for the diffusion co-efficient and characteristics of the concentration gradient. The diffusion co-efficient is in turn a function of temperature and carbon concentration. The diffusion of carbon proceeds from the higher concentration, developed from the supply source, to the lower concentration of the core; when the concentration limits are maintained consistently, the form of the gradient may be predicted for any given and constant temperature of operation⁴.

The general form of the carbon gradient is influenced only by the range of concentration from surface to the core. For a given temperature, the rate of diffusion increases with increasing carbon concentration. For common carburizing steels and practice, the surface concentration limits

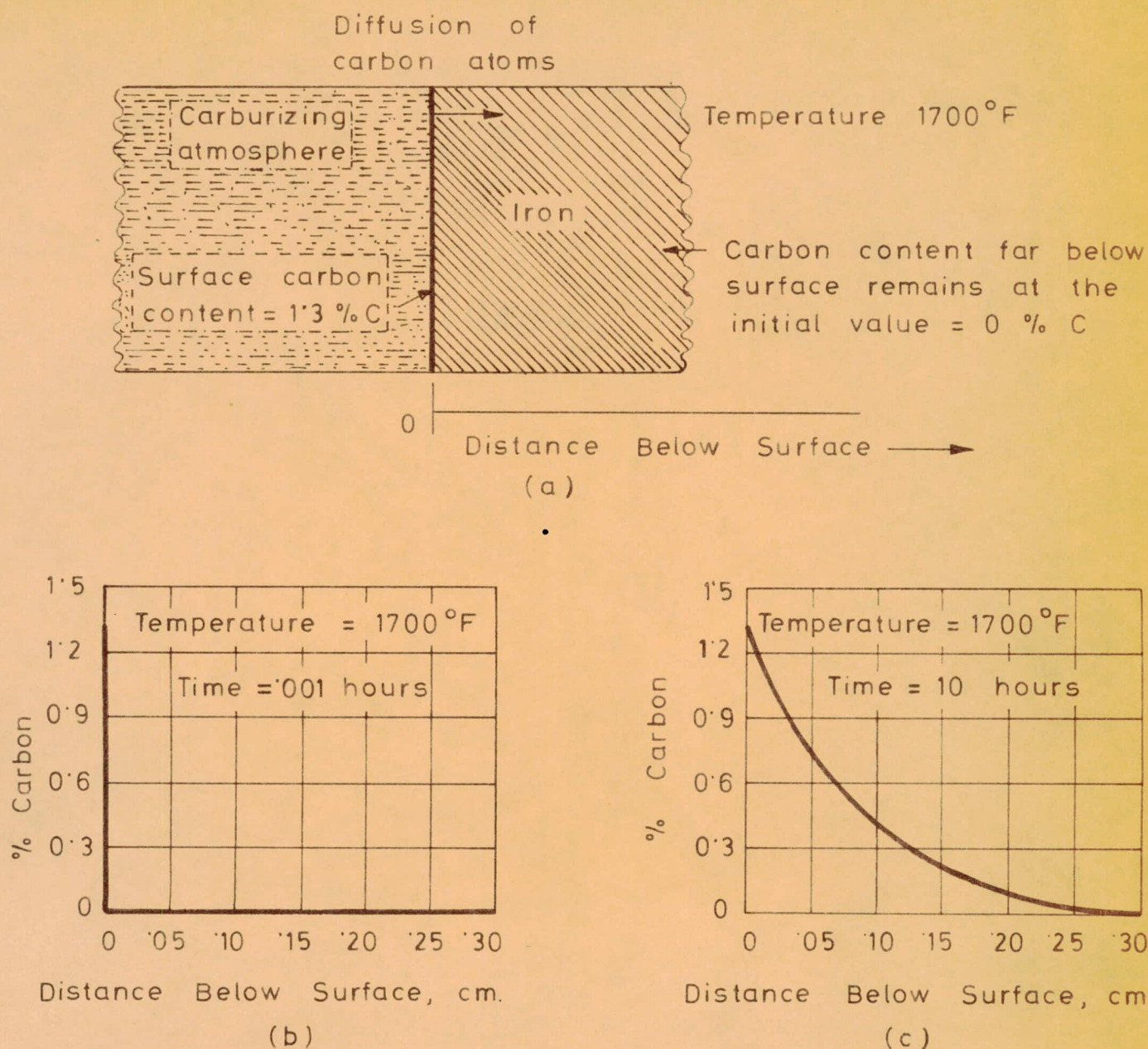


Fig. 3. The diffusion of carbon in iron during carburizing. (a) Schematic representation of the procedure used in carburizing an iron plate. (b) Carbon penetration curve near the beginning of the carburizing process, and (c) after 10 hours.⁶

are from from 1.0 to 1.3% C with core concentrations usually from 0.12 to 0.25% C⁴. For its attainment, the standard carbon gradient obviously requires a constant temperature of operation and a sufficient supply of carbon to the steel surface.

The case depth for a carburized machine parts may be considered to be the extent of carbon concentration which on heat-treatment provides the desired uniform mechanical properties. The case depth for a carburized steel is a function of temperature and time. It has already been mentioned that higher the temperature the greater will be the rate of carbon diffusion and thus deeper will be the case depth. Experiment shows that 40% more⁷ will be the rate of diffusion by 100°F rise of temperature, say from 1600°F to 1700°F.

For consistent results in carburizing, it is important that the temperature be uniform. Uniformity in various locations throughout the work load depends on the furnace design, load density, recirculation and heating rate. For a given density of load the difference in temperature between the outer and inner portions of the load may be high at carburizing temperatures, because the outside of the load is heated primarily by radiation and the rate of heating is rapid to reach to carburizing temperature. For better control of temperature, the thermocouple should be placed as close as possible to the work.

F.E. Harris⁷ has developed a formula for the effect of time and temperature on case depth for normal carburizing:

$$\text{Case depth} = \frac{31.6 \sqrt{t}}{10^{(6700/T)}} ,$$

where case depth is in inches; t is time at temperature, in hours; and T is the absolute temperature, in degrees Rankine.

For a specific carburizing temperature, the relationship becomes simply:

$$\begin{aligned}\text{Case depth} &= K \sqrt{t} \\ &= 0.025 \sqrt{t} \text{ for } 1700^{\circ}\text{F} \\ &= 0.021 \sqrt{t} \text{ for } 1650^{\circ}\text{F} \\ &= 0.018 \sqrt{t} \text{ for } 1600^{\circ}\text{F}\end{aligned}$$

When carburizing is purposely controlled to produce surface carbon concentrations somewhat less than saturated austenite, the case depth will be slightly less than the Harris equation shows. The case depth determined by the equation is total case depth, and for case depths in the range from 0.040 to 0.070 inch it will correspond to a point on the carbon gradient where the carbon concentration is about 0.07% C higher than the carbon content of the core⁷.

In addition to the time at carburizing temperature several hours may be required for bringing the work to operating temperature. For work quenched directly from the carburizer, the cycle may be further lengthened to allow time for the work to cool from carburizing temperature to a quenching temperature of perhaps 1550°F. Although some diffusion of carbon from case to core occurs during this time, diffusion is slower than it would be at the carburizing temperature. This period may be used deliberately as a moderate diffusion period to lower the carbon concentration at the surface by maintaining an atmosphere of low carbon potential in contact with the work during this time⁷.

F.E. Harris⁷ has also developed a method for calculating the carburizing time and diffusion time to produce a carburized case of predetermined depth and carbon concentration at the surface:

$$\text{Carburizing time} = \text{Total time} \left(\frac{C - C_1}{C_0 - C_1} \right)^2$$

and

$$\text{Diffusion time} = \text{Total} - \text{carburizing time}$$

where total time in hours, C is the final desired surface carbon concentration, C_0 is the surface carbon concentration at the end of carburizing cycle, and C_1 is the concentration of carbon at the core. Effect of carburizing time and temperature on case depth obtained in gas carburizing is shown in Fig. 4

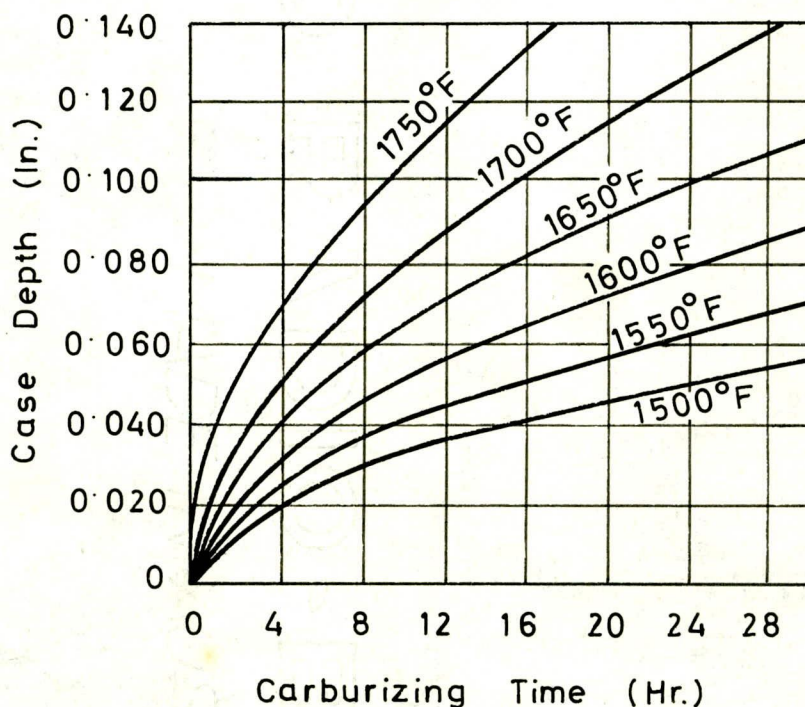


Fig. 4 Depth of Carbon Penetration for Different Times and Different Temperatures in Gas Carburizing an SAE 1020 Steel (After Williams, Symposium on Carburizing)⁸.

The carbon added through the surface area is directly proportional to the case depth. The carbon that has been absorbed during carburization by a machine part (steel) of say 1 square feet surface area for a case depth of $1/20$ inches may be calculated in the following way. The carburizing temperature may be taken 1700°F at which the concentration of carbon at the case may be taken to be 1.2 percent.

Let the machine part contains originally 0.2 percent carbon. Then carbon spread will be equal to surface % carbon minus core % carbon.

Now for the area of 1 sq.ft. or 144 sq. inches, the effective volume of the machine part made of steel

$$= (144) \times (\text{Case depth in inches})$$

$$= (144) \times (1/20) \text{ cubic inches}$$

$$\therefore \text{Weight of this volume in pounds} = (144) \times (1/20) \times (0.28) \text{ lbs.}$$

$$[\because 1 \text{ in.}^3 \text{ of steel weighs } 0.28 \text{ lb.}]$$

The average increase in percentage concentration is represented by one half of carbon spread from surface to a depth of 0.6% carbon and the numerical factor for carbon added during carburization becomes $1/2 \times 1/100 \times (\text{carbon spread})$

$$= 1/2 \times 1/100 \times [(1.2 - 0.2) + (0.6 - 0.2)]$$

$$= 1/2 \times 1/100 \times (1.4)$$

$$= 0.70/100 \text{ parts}$$

$\therefore$ the amount of carbon in pounds absorbed through each sq.ft. of surface area

$$= (144) \times (0.28) \times (1/20) \times (0.70/100)$$

$$= 0.014 \text{ lbs.}$$

Diffusion co-efficients vary with the nature of the solute atoms, with the nature of the solid structure, and with changes in temperature. Higher temperatures provide higher diffusion co-efficients, because the atoms have higher thermal energies and therefore, greater probabilities of being activated over the energy barrier between atoms as shown in Fig.7. Carbon has a higher diffusion co-efficient in iron because the carbon atom is small one. Atoms have higher diffusion co-efficients in bcc iron than in fcc iron because the former has a lower atomic packing factor⁵.

The diffusion proceeds more rapidly along the grain boundaries because this is a zone of crystal imperfections⁵. At the grain boundaries between two adjacent grains there is a transition zone which is not aligned with either grains as shown in Fig. 5. The mismatch of the orientation of adjacent grains produce a less efficient packing of the atoms along the boundary. Thus the atoms along the boundary have a higher energy than those within the grains. This higher energy of the boundary atoms is important for the nucleation of polymorphic phase changes and the lower atomic packing along the boundary favours atomic diffusion.

Other crystal imperfections namely point defects facilitate atomic diffusion more rapidly. Interstitialcies is the most prominent point defect which favours diffusion of carbon in iron and steel. It arises when an extra atom is lodged within a crystal structure particularly if the

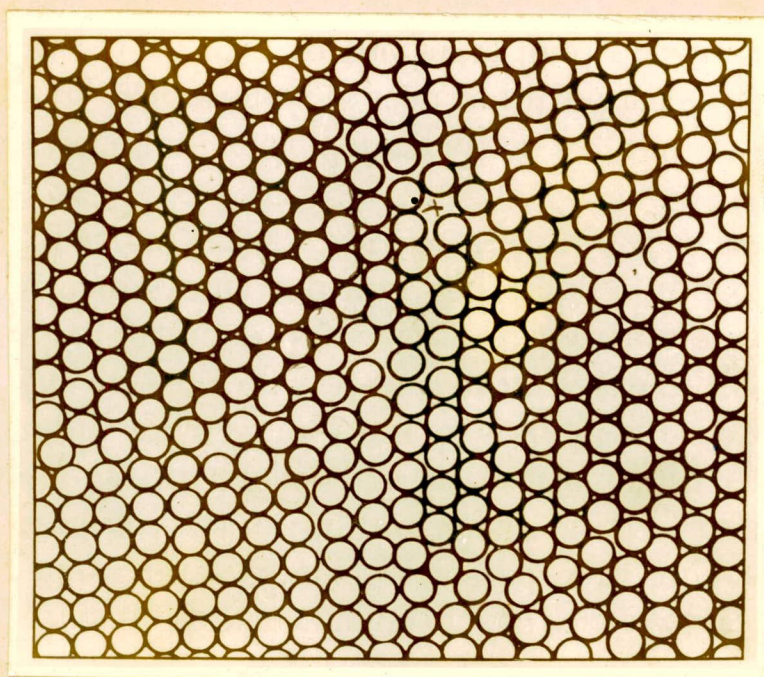


Fig. 5 Grain boundaries. Note the area of disorder at the boundary⁵.



atomic packing factor is low. Such an imperfection produces atomic distortion as shown in Fig. 6, unless the interstitial atom is smaller than the rest of the atoms in the crystal.

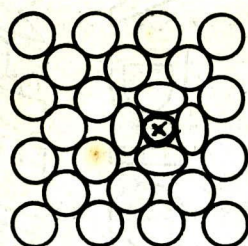


Fig. 6 Point defects : Interstitialcy⁵

The interstitial mechanism moves atoms among the neighbouring atoms of the crystal structure shown in Fig. 7.

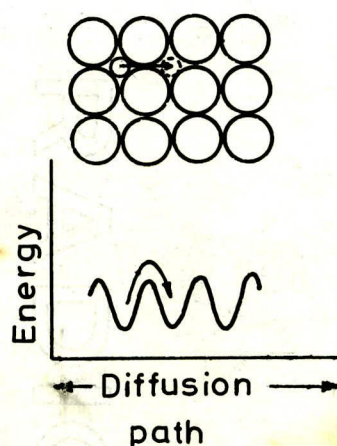


Fig. 7 Atom movements : Interstitial mechanism⁵

The interstitial atom of Fig. 7 has an equal probability of moving in the six coordinate directions. If the atoms are to change locations, the "energy ridges" of Fig. 7 must be overcome. The energy required to overcome them is called the activation energy of diffusion. With interstitial diffusion, energy is required to force the atom into closer contact with neighbouring atoms as it moves among them. The activation energy varies with a number of factors. For example, a small atom has a lower activation energy than a larger atom or a molecule. Therefore, interstitial movements require more energy than vacancy movements⁵.

Flow of carbon from the supply source: The primary function of carburizing mediums is to furnish an adequate supply of carbon to the steel surface. The transfer of carbon from the source of supply to the steel is involved with reactions occurring at this surface. The carburizing agent responsible for the actual transfer of carbon is a carbon compound. The extent to which various carbon compound may supply carbon is related to the conditions that determine the equilibrium with the surface carbon of the steel. The equilibrium composition of the reactants and products is a function of temperature and also of the carbon concentration at the surface.

Low carbon steels when heated to the carburizing temperature, will be completely transformed into austenite. At the carburizing temperature austenitic iron is capable of holding in solid solution an amount of carbon approaching the saturation limit of 1.7 percent. When a source of carbon, such as carbon monoxide is brought into contact with the steel in this condition, there will be a transfer of carbon from the gas to the steel. There is a difference of opinion⁹ as to the exact form of the carbon;

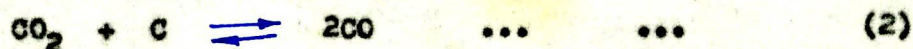
Some feel that there is an interaction of the carbon monoxide and the iron to form iron carbides, which are then absorbed by the steel; others feel that the carbon being brought to the surface of the metal as carbon monoxide will, in the presence of austenite, break down to form atomic carbon, which will diffuse as such in the iron. For our present purpose of discussion let us assume that the action involving the formation, absorption and diffusion of carbon into iron is the essential part of the carburizing process.

In pack carburization the carburizing compound is in reality the gas producer. In other words, the carbon monoxide is the result of the reaction between the carbonaceous compound and the oxygen from the air, the air in this case being the air occluded with the compound particles. The CO thus formed will give up its carbon to the iron according to the following equations:



Without a further supply of CO this reaction between CO, CO₂, and austenite would soon reach equilibrium and carburizing would stop. Herty⁹ states the CO : CO₂ ratio must be above 24 for this reaction (1) to proceed and also that the rate of penetration must be about 0.01 to 0.02 mm per hour.

Since, at carburizing temperature, there is always a large amount of incandescent carbon present, the CO₂ will be constantly reduced, so that there will be a continuous supply of CO according to the reaction:



This cycle continues to repeat itself, and the process of carburizing will continue as long as the proper temperatures are maintained and the

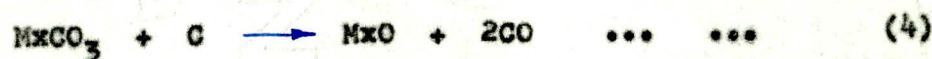
CO : CO₂ is kept high enough. In this case the carbon will be absorbed, the concentration of carbon will be built up at the surface and will then move inward according to the simple laws of diffusion of heat or dissolved substances, i.e. from a region of high concentration to one of lower concentration as stated earlier. The carburizing phase of casehardening is, thus, one of absorption at the surface plus inward migration.

Since the usual carburizing compounds have incorporated in them one or more of the carbonates of alkaline or alkaline earth metals it is generally considered that they may react according to the following equations:



The M is any metal of the alkaline or alkaline-earth group. The CO₂ formed will react with hot carbonaceous packing, as in reaction (2), and will increase the concentration of available CO.

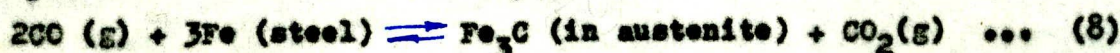
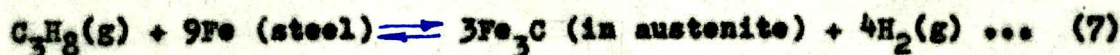
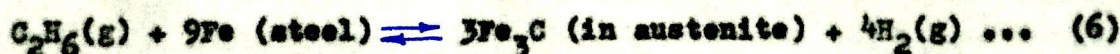
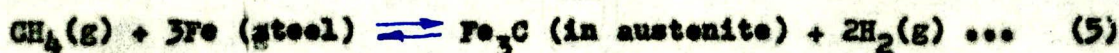
It is also believed that the carbonate reacts with the hot carbon:



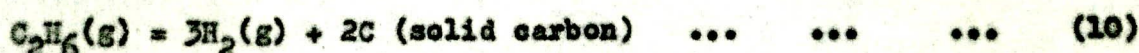
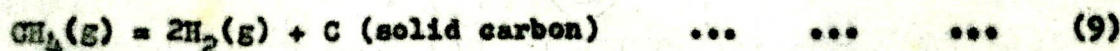
and that the oxide thus formed will act as a catalyst between the reaction of the CO and the iron.

In gas carburizing, the carbon of the furnace atmosphere is in the form of gaseous hydrocarbon compounds such as methane, ethane, propane and butane or carbon monoxide. The principal source of carbon in gas carburizing is methane which is present in manufactured and in natural gas.

The reactions involving the actual transfer of carbon occur at the steel surface (interface) and the reactants, which are carbon compounds, may be considered independently. The interface reactions¹⁰ for common carbon compounds may be written:



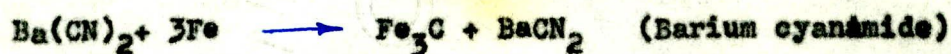
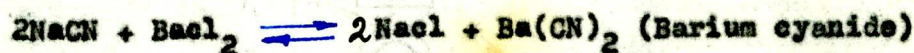
Considering the reactions that occur for the same compounds, away from the interface, the reactions for deposition of carbon¹⁰ are expressed:



The reactions, specially (5) and (8) are definitely reversible reactions at carburizing temperature. Pure CO_2 would decarburize steel to form CO by reversing reaction (8) and pure H_2 would decarburize steel by forming CH_4 , the reverse of equation (5). If water vapour is present in the gas it will act as a decarburizing agent, removing carbon from steel by the reaction¹⁰



In liquid carburisation, the carburizing action depends primarily on the sodium cyanide, activated by the presence of alkaline earth salts - usually barium (or calcium) chlorides. The salts (chloride) reacts with the cyanide to form a cyanide of alkaline earth metal, which then reacts with iron to form Fe_3C . The basic reactions⁸ may be represented by the equation:



The carbon liberated by the shift from barium cyanide to barium cyanamide, is absorbed by the steel and the small amount of nitrogen available

is absorbed producing a beneficial effect on the file hardness of the surface.

The object of carburization is to develop hard, wear resistant surface and a tough core in some moving machine parts. Carburization mainly provides the concentration of carbon on the surface to a case depth of about $1/20$ to $1/16$ inch. The mechanical properties of the machine part will be obviously different for the case and the core due to differential concentration of carbon and may not be sufficient enough to respond the desired properties wanted from the carburized machine part. Fig. 8 represents the microstructure of a carburized machine part which is normally cooled in the furnace. Hence the carburized machine parts are heat-treated to get higher mechanical properties namely hardness at the surface and toughness at the core. Since the carburized machine part gets variable carbon concentration in it, a double heat-treatment is recommended. One for the core which is expected to be tough and the other for the case which is desired to be hard, wear-resistant. Highly satisfactory results are obtained by heating the carburized machine part 100°F above its upper critical temperature as far as its core carbon percentage is concerned and then quenched in water.

The machine part is again heated to a temperature 60°F above its lower critical temperature followed by water or oil quenching and tempering below 700°F . This method of heat-treatment is schematically



FIG. 8 Carburized Steel (100×)
High-Carbon Case at Top
Low-Carbon Core at Bottom 8



presented in Fig.9.

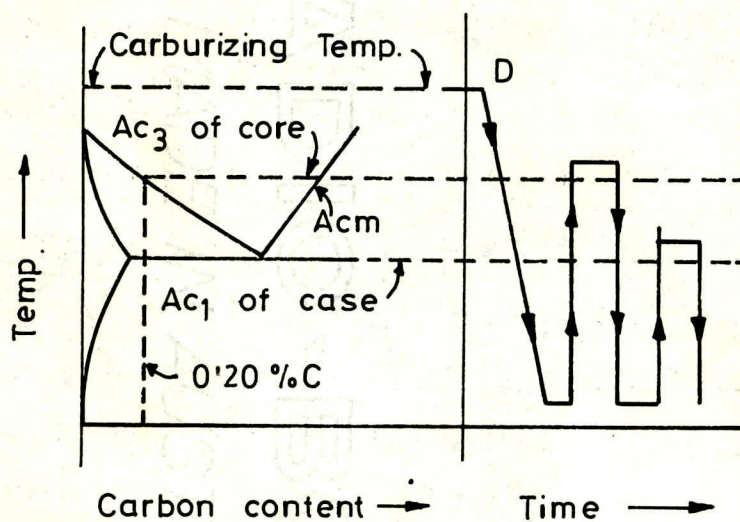


Fig. No. 9

Double heat-treatment will thus give best combination of a hard wear-resistant fine grained case and a tough and refined core Fig. 10.

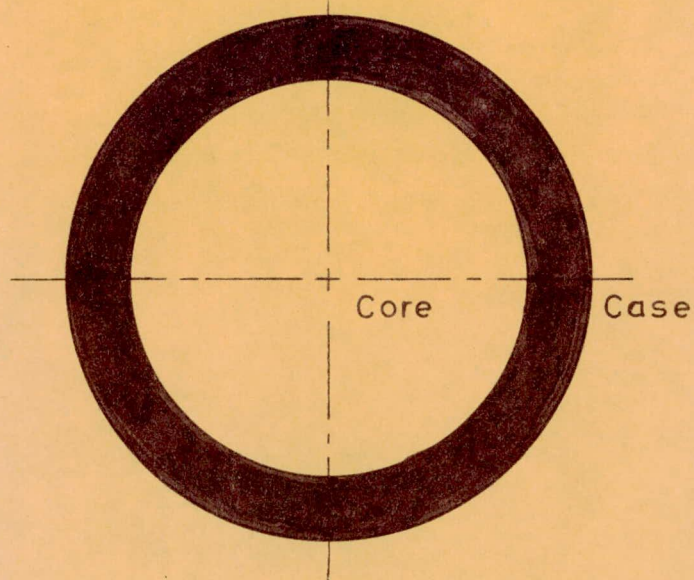
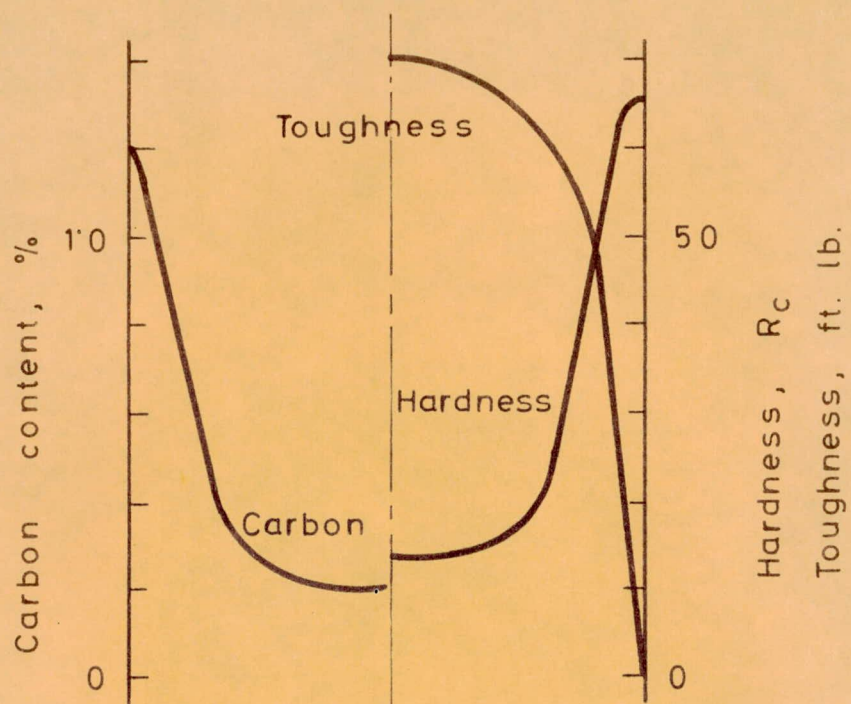


FIGURE NO. 10⁵

RADIO-BOND

CHAPTER - III

EXPERIMENTAL SET-UP

RADIO-BOND

EXPERIMENTAL SET-UP

The experiments were conducted in a gas fired furnace built by fire clay bricks (Fig. No. 11). The furnace is of rectangular cross-section having $4\frac{1}{2}$ " wall thickness, external dimension being 42"x36"x32". The side walls are provided with circular holes for fitting the experimental chamber that will contain the Titas gas and the specimens to be carburized. The roof of the furnace consists of slabs made of fire brick chips and fireclay cement. A short stem chimney is provided at the centre of the slab for the escape of exhaust flue gases. The back wall of the furnace contains two $\frac{1}{4}$ " circular holes for the insertion of thermocouple to record the temperature of the furnace.

The furnace is fired through two burners from the front. A schematic diagram (Fig. No. 12) shows the arrangement of the burners. The flame of the burner is adjusted by trial so that it may not reflect back. Firing by gas alone requires about 2 to 3 hours time to get the required carburizing temperature say 900°C . Firing with a mixture of air and gas requires half an hour time to raise the required temperature of 900°C . Most of the experiments are conducted while the furnace was heated by a mixture of air and gas.

The experimental chamber containing the specimens and gas is a cast iron pipe of about 3" internal diameter and 54" length of which 32" is effective length supported from the side walls at a height of about 12" from the bottom of the furnace. Just out side the furnace body, one end of the experimental pipe is connected with a reducing socket for the flow of Titas gas into the chamber during the carburizing period while the other end of the pipe is fitted with a threaded flange so that this end of the

Scale : 1" = 10"

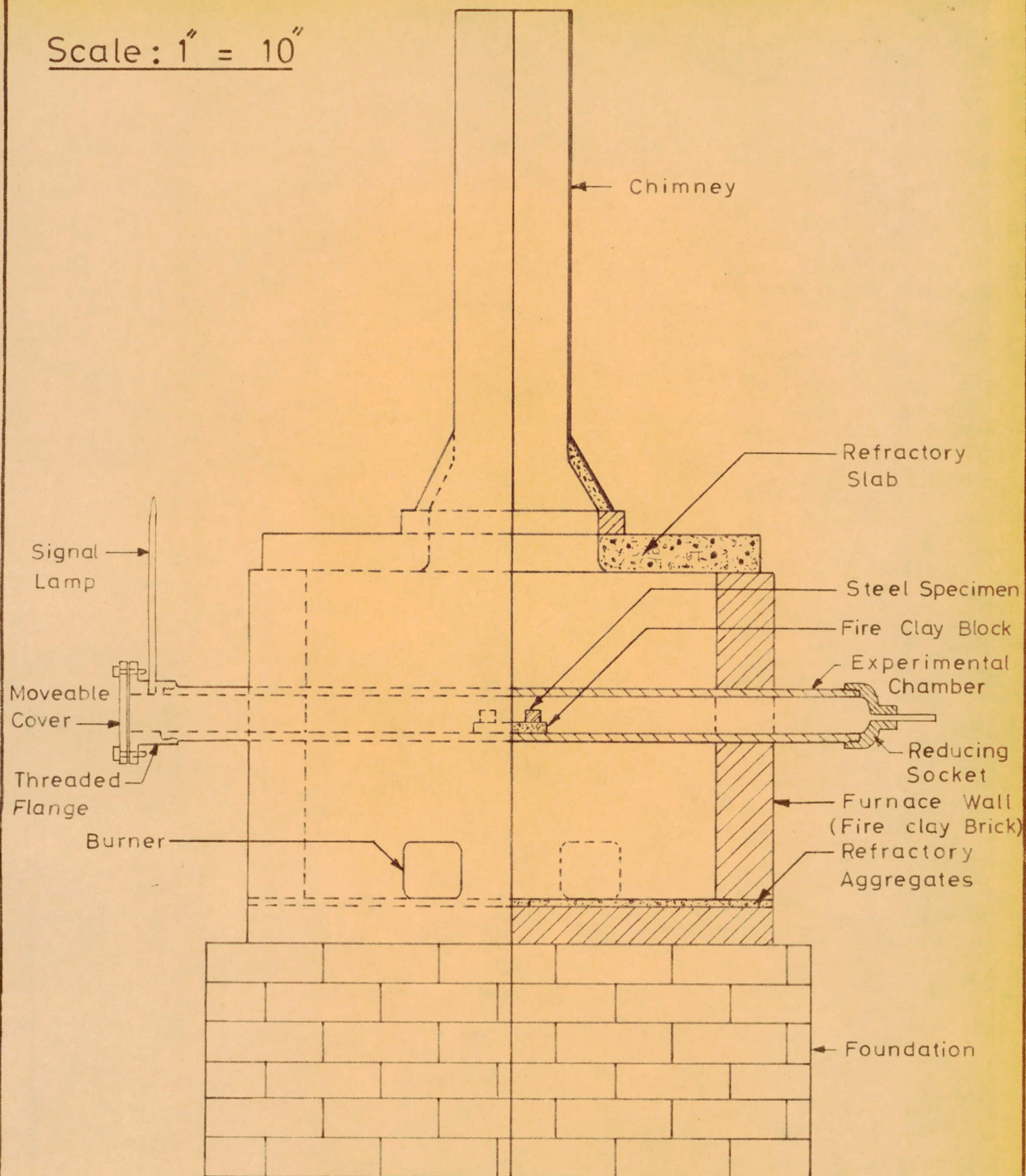


Fig. 11 Half Sectional Elevation

- | | |
|-------------------------|----------------------|
| 1 Furnace Body | 13 Reducing Socket |
| 2 Experimental Chamber | 14 Controlling Valve |
| 3 Burner | 15 Air Chamber |
| 4 Refractory Slab | 16 Gas Chamber |
| 5 Chimney | 17 Nozzle |
| 6 Fire Clay Block | 18 Blower |
| 7 Steel Specimen | 19 Flowrator Meter |
| 8 Signal Lamp | |
| 9 Thermocouple | |
| 10 Threaded Flange | |
| 11 Moveable Cover | |
| 12 Indicating Pyrometer | |

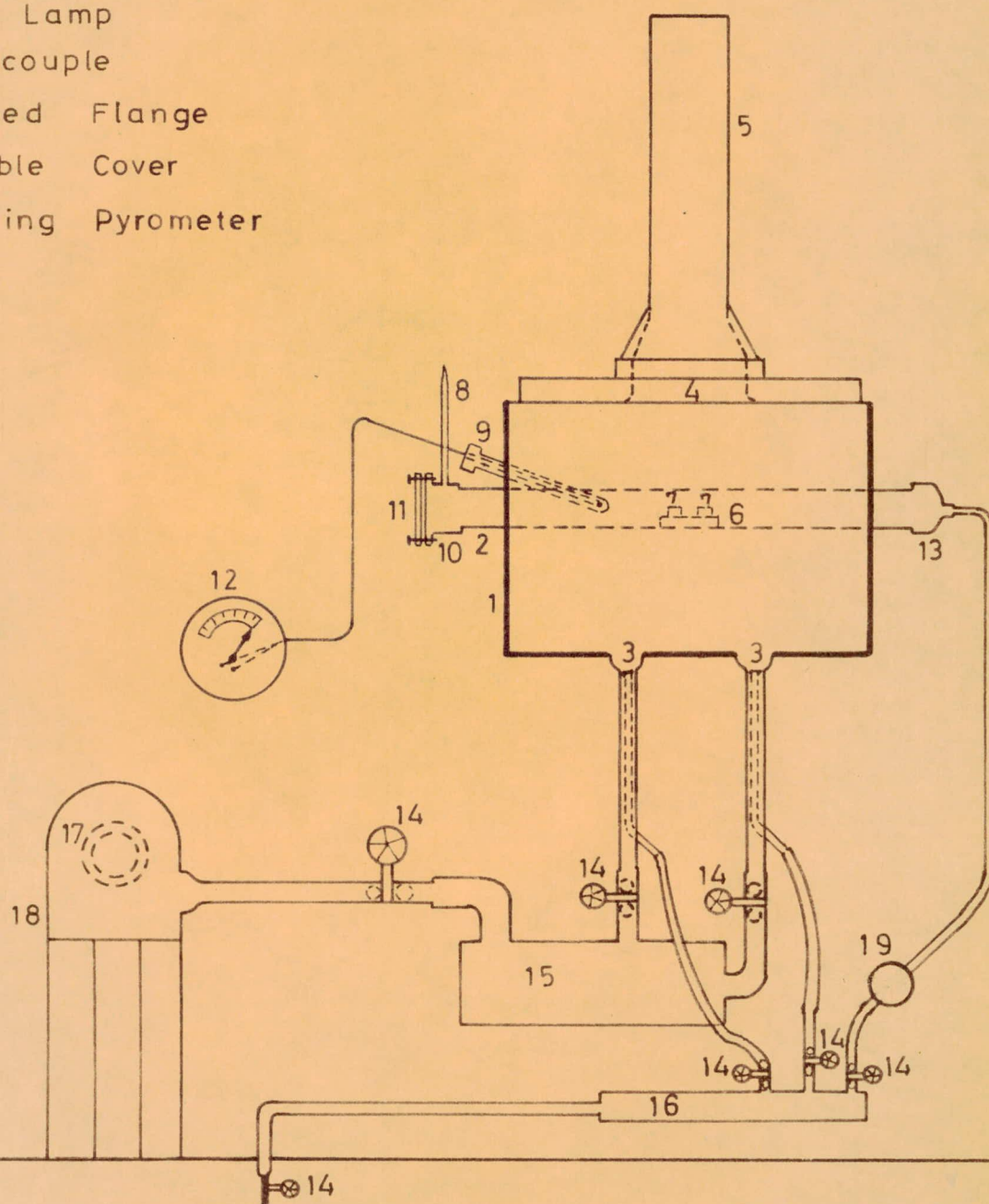


Fig. 12 Schematic diagram of the experimental set-up.

pipe is closed with a moveable cover. This cover is fitted gas tight with the flange so that it can be opened and closed during the experiments. This arrangement helps the withdrawal of specimens after the appointed time of carburization. Towards this end a $3/16$ " exit hole is provided so that a thin stream of excess gas escapes from the experimental chamber. So long a thin flame is visible at this exit hole through a glass jet, the operator can be sure that the chamber contains the gas and the specimens are exposed to the experimental gas whose carburizing property is going to be determined. A Flowrator Meter is placed in between the gas chamber and the experimental chamber to measure the amount of gas flown during the experiment.

The specimens are of low carbon mild steel whose carbon content was initially determined to be 0.20% as evident from microstructure of Fig. No.13. About fifty specimens of $3/4$ " diameter but $1/2$ " thick were prepared for the experiment. Since the experimental chamber is a circular pipe, a semi-circular fireclay block of 6" long and of 3" in diameter was used for placing these specimens inside the chamber. Three specimens were taken for each set of experiment and they were placed at one inch apart on the fire clay block.

Just before the firing of the furnace the cover of the experimental chamber was opened. The fireclay block and the specimens were placed just at the center of the chamber i.e. near the central part of the furnace body and the cover was replaced. The gas was then introduced into the chamber to wash away the air through the exit hole. On ignition when a steady flame was visible at the glass jet as shown in Fig. No. 14, it was



Fig.No.13 Microstructure of original low carbon mild steel specimen (150 X).

then taken that the chamber was fully of gas. The furnace body was then ready for firing. Suitable mixture of air and gas showed that 25 to 30 minutes time was sufficient to raise the temperature of 900 - 925°C.

A chromel-alumel thermocouple was inserted through the hole on the back wall. Care was taken so that the hot junction of the thermocouple might not touch the chamber but remained within 1/4 to 1/2" close to the chamber. When the carburizing temperature was reached, the supply of air and gas were manually controlled to maintain a steady temperature as shown in Fig. No. 14.

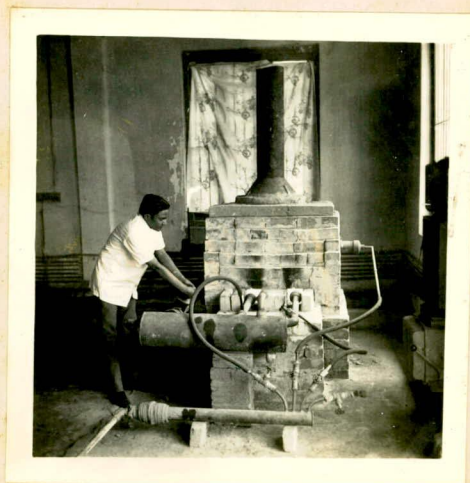


Fig.No. 14

The author is checking the flow of air and gas.

MADE IN AUSTRIA

RADIO-BOND

CHAPTER - IV

EXPERIMENTS AND RESULTS

MADE IN AUSTRIA

RADIO-BOND

EXPERIMENTS AND RESULTS

The experiments conducted may be classified into four categories on the basis of temperature as shown in the attached chart. The specimens are heated at four different temperatures viz. 850°C , 875°C , 900°C and 925°C . The duration of holding time at each category of temperature is selected for $1\frac{1}{2}$ hours, 2 hours and $2\frac{1}{2}$ hours time. After heating for the appointed time of $1\frac{1}{2}$ hours, 2 hours or $2\frac{1}{2}$ hours, the firing of the furnace was discontinued and the specimens were allowed to cool in the heating chamber.

When the room temperature was reached, the specimens were withdrawn and transverse sections of the carburized specimens were prepared for micro-examination. The etched specimens when viewed under microscope showed zones of hypereutectoid, eutectoid and pro-eutectoid structure of different grain sizes from the surface towards the core and in some cases only eutectoid and pro-eutectoid depending on the time of exposure and temperature.

The sizes of the grains in the different specimens were found different. For a specimen when heated at a constant temperature showing various zones of hypereutectoid, eutectoid etc. will not develop theoretically uniform grain sizes because they do not contain uniform carbon. According to the thermal equilibrium diagram of iron and iron-carbide, different steel specimens with variable percentage of carbon show different grain sizes.

Attempt has therefore, been made to find the extent of carburization i.e., the effective case depth. The effective case depth may include the depth which under microscope shows the zones of hypereutectoid, eutectoid

and pro-eutectoid containing carbon upto 0.60 percent, since steel specimens show maximum hardness on heat-treatment from 0.6 percent carbon as shown in Fig. No. 15.

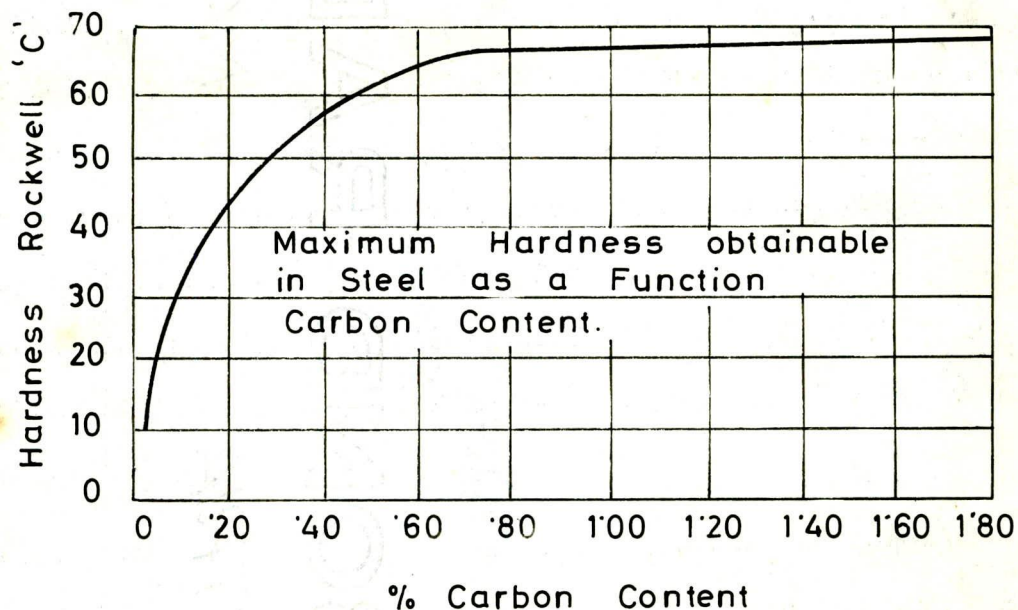
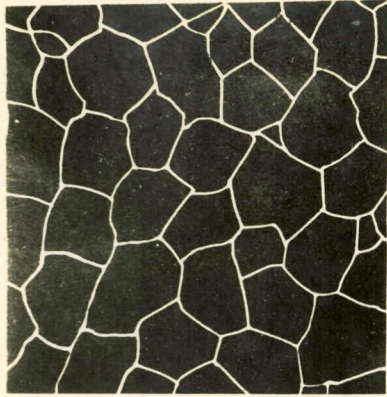
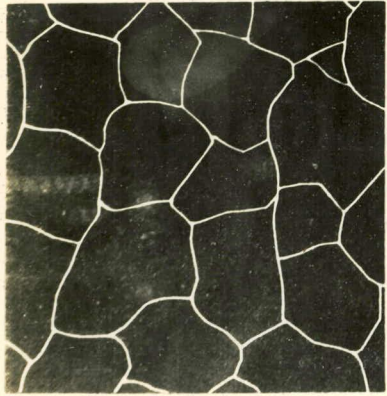


Fig. 15 Maximum Hardness Vs Carbon Content for Steels.¹¹

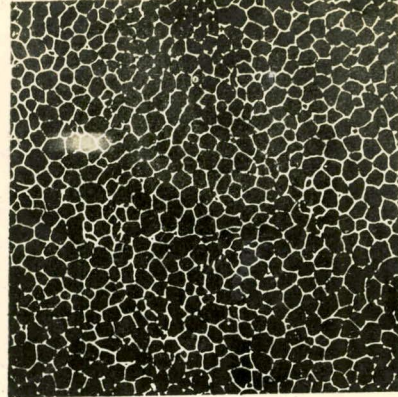
The size of the grains for the effective case depth was compared with a chart listing a series of eight ASTM standard grain sizes¹² as shown in Fig. No. 16. Since the grain size of the eutectoid zone was very difficult to determine at low magnification, the average grain size numbers were noted by seeing the grain size of the hyper eutectoid and pro-eutectoid zones at 100 X. Mean number of grains per in². at 100 X corresponding to each grain size number were taken from the ASTM grain size table No. 1. Then the linear case depths were calculated by noting the total number of grains of the carburized portion.



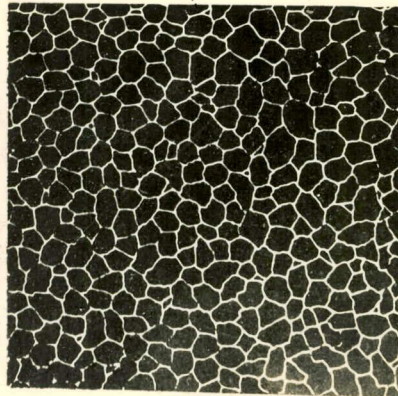
No. 4



No. 3

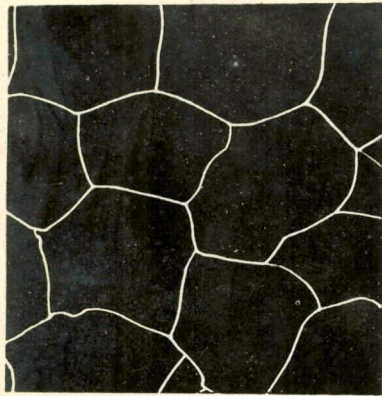


No. 8

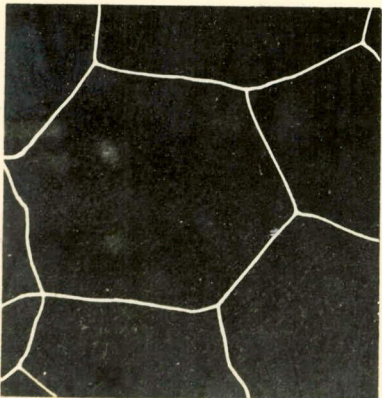


No. 7

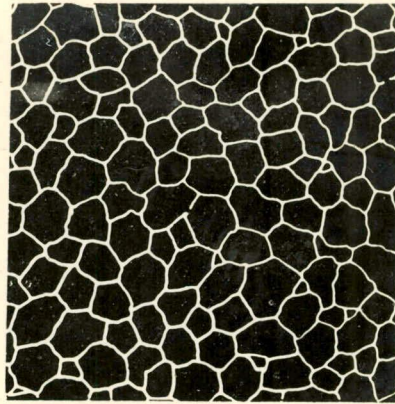
FIG. 16—GRAIN-SIZE CHART (A.S.T.M. STANDARDS)



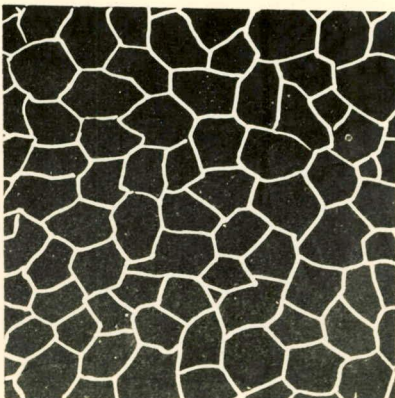
No. 2



No. 1



No. 6



No. 5

FIG. 16—GRAIN-SIZE CHART (A.S.T.M. STANDARDS)

The chart No. 1 provides the extent of case depths for different period of carburization for each category of temperature. The detail calculations for some case depth are also given in Appendix-A. The case depth for each different temperature is then plotted as a function of holding time as shown in graph of Fig. No. 17.

The micro-structure of the carburized specimens for various time shows clearly the extent of carburization for different categories of temperature in Fig. Nos. 18 to 21. The different microstructure shows the variable case depth i.e. variable extent of carburization.

To compare the rate of carburization among Titas Gas, solid carbon (charcoal) and a conventional carburizing mixture, some experiments were conducted. A mild steel shaft of about 0.22 percent carbon was selected for this purpose. The steel block was drilled to make four $\frac{3}{8}$ " bores. Two bores were filled with good charcoal and the others with carburizing mixture as shown in Fig. No. 22 and rammed tightly. The bores were then plugged. It was

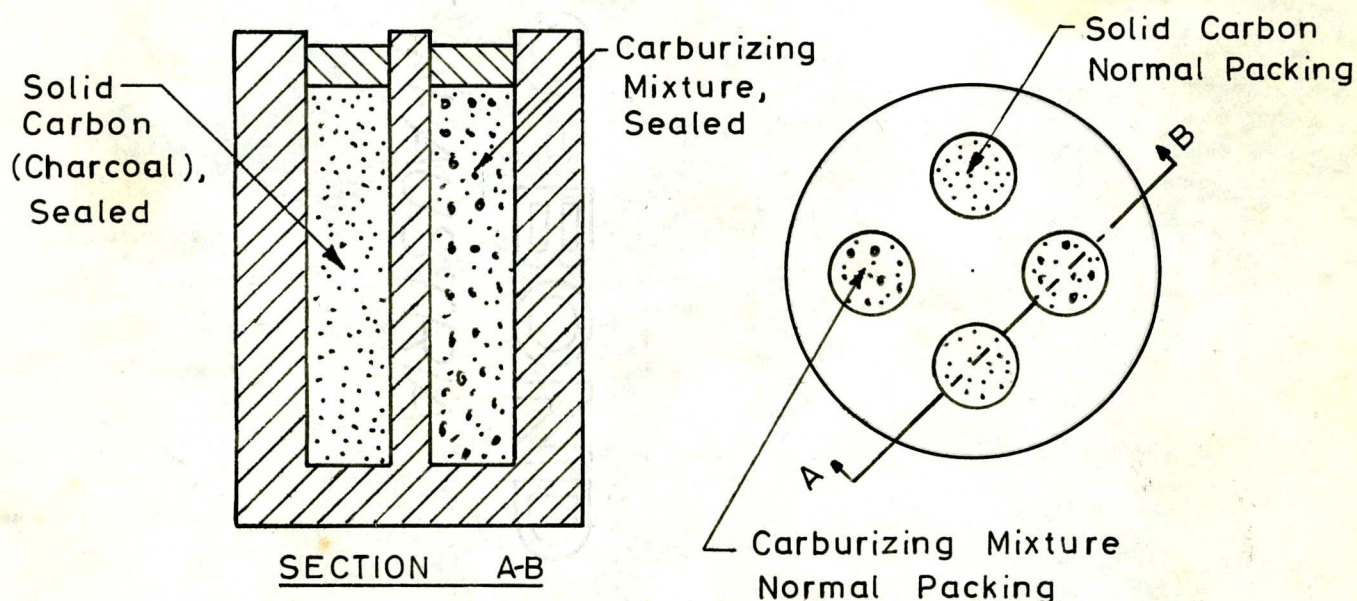


FIG. NO. 22

then placed in the experimental chamber containing Titas Gas. The chamber was then heated to the appointed time of $2\frac{1}{2}$ hours at 925°C . After steady temperature of 925°C for $2\frac{1}{2}$ hours, the steel block was cooled slowly in the chamber before being withdrawn at room temperature. The block was then ready for plishing and micro-examination to study the comparative rate of carburization. The result of carburization by gas, solid carbon and carburizing mixture is given in chart No.2. The micro-structure of the carburized shaft given in Fig. Nos. 23 to 25 shows the extent of carburization by Titas Gas, solid carbon and carburizing mixture.

The microstructure shows that the extent of carburization by Titas Gas is more than the carburizing mixture. Again the microstructure reveals that the rate of carburization by solid charcoal is less than the carburizing mixture. On bore of each carburizing mixture and charcoal was plugged by a small piece of steel rod to generate pressure during heating and to see whether there is any variation in the extent of carburization by pressure. Microstructure of Fig. Nos. 23(b) and 24(b) shows that the extent of carburization is more due to pressure.

During some of the experiments the amount of gas required during heating the chamber and maintaining the specimens at constant temperature was recorded from Flowrator Meter to calculate the economical aspect of carburizing media shown by chart No. 3. Necessary calculations are given in Appendix-B.

TABLE NO. 1 , ASTM GRAIN SIZE⁸

	<u>ASTM NO.</u>	<u>Mean Number of grains per in.² at 100 X</u>	<u>Grain per mm²</u>
	-3	0.06	1
	-2	0.12	2
	-1	0.25	4
	0	0.5	8
Usual range	1	1	16
	2	2	32
	3	4	64
	4	8	128
	5	16	256
	6	32	512
	7	64	1024
	8	128	2048
	9	256	4096
	10	512	8200
	11	1024	16400
	12	2048	32800

CHART NO. 1

Category	Holding Temperature, °C	Experiment No.	Holding Time, hr.	Average grain size Number at 100X	Mean Number of grains per in ² . at 100X	Mean Length of grain in inch at 100X	Mean length of grain at normal size, inch.	Total number of grains present in the carburized case when viewed linearly from surface towards core.	Case depth, inch.
1	850°C	1	1½	3	4	0.50	0.0050	4	0.020
		2	2	4	8	0.35	0.0035	7	0.0245
		3	2½	3	4	0.50	0.0050	5	0.025
2	875°C	4	1½	4	8	0.35	0.0035	7	0.0245
		5	2	4	8	0.35	0.0035	8	0.028
		6	2½	3	4	0.50	0.0050	6	0.030
3	900°C	7	1½	4	8	0.35	0.0035	10	0.035
		8	2	3	4	0.50	0.0050	8	0.040
		9	2½	3	4	0.50	0.0050	9	0.045
4	925°C	10	1½	3	4	0.50	0.0050	9	0.045
		11	2	3	4	0.50	0.0050	11	0.055
		12	2½	2	2	0.70	0.0070	9	0.063

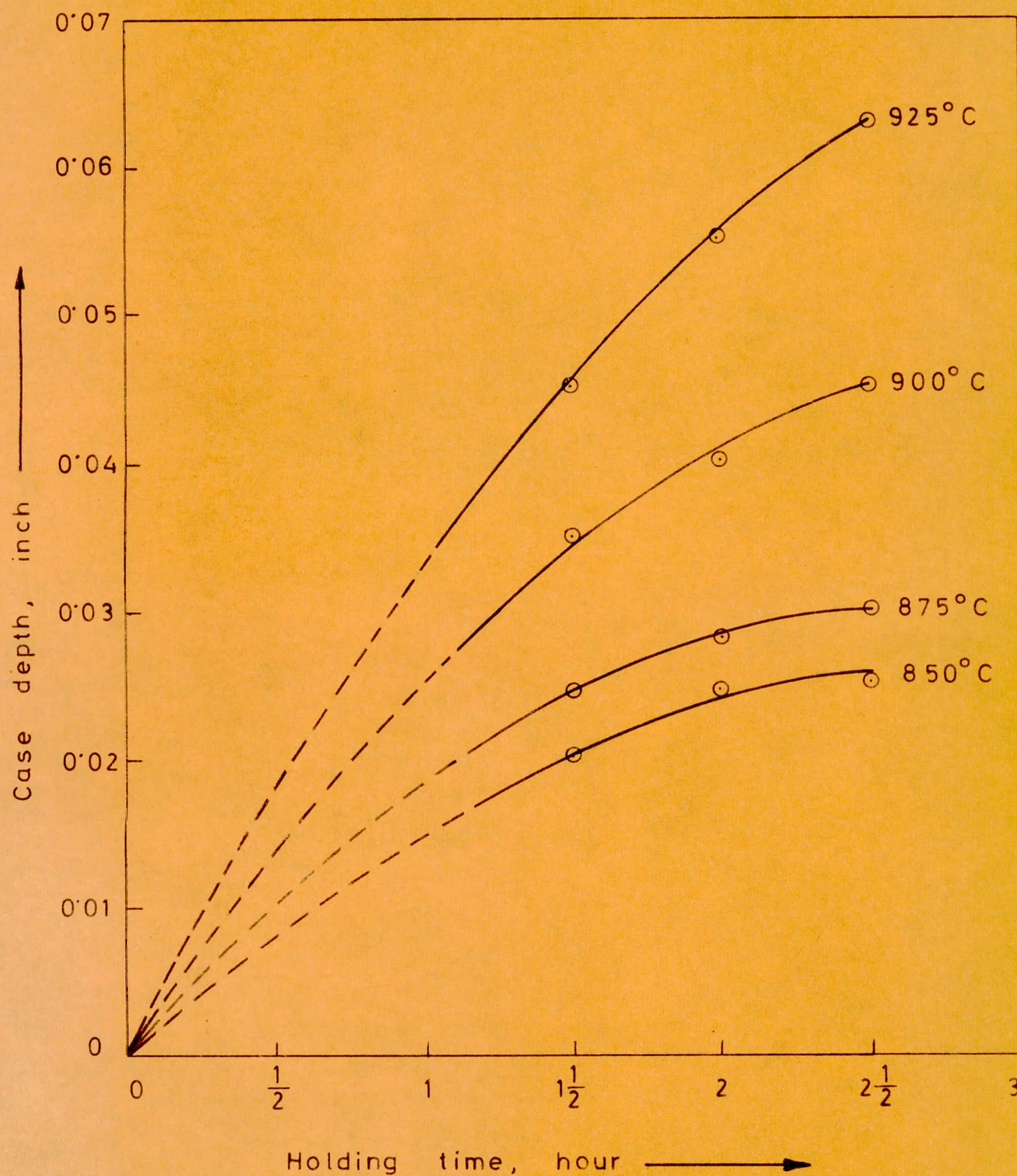


Fig. 17. Depth of carbon penetration for different times and different temperatures in gas carburizing (Titas gas).

CHART NO. 2

CHART NO. 2

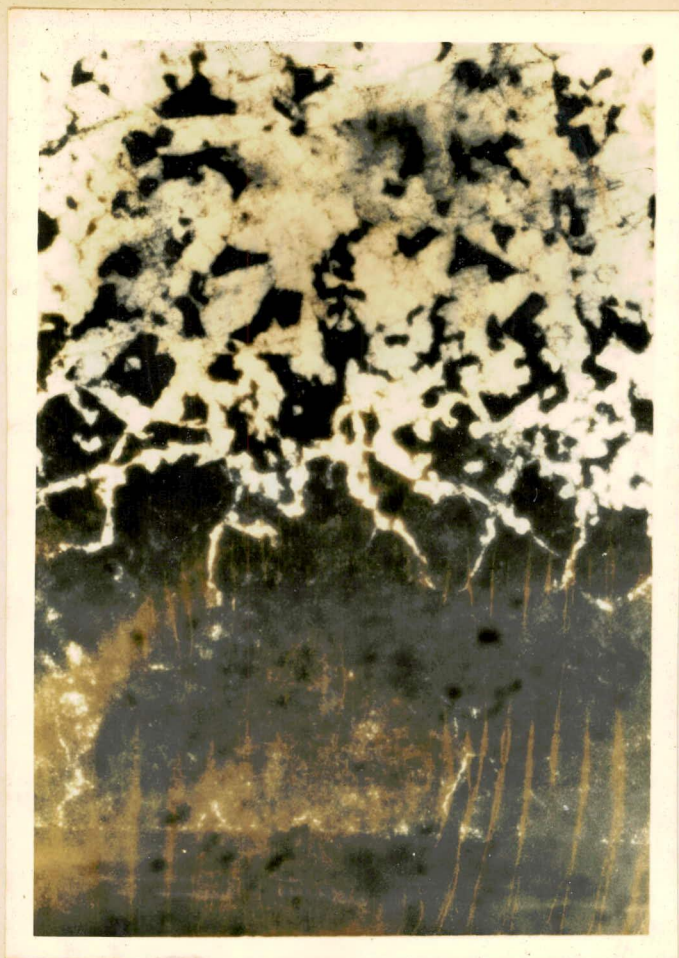
Carburizing Medium	Type of packing	Holding temp., °C	Holding time, hr.	Average grain size number at 100X	Mean number of grains per in. ² at 100X	Mean length of grain in inch at 100X	Mean length of grain at normal size, inch.	Total number of grains present in the carburized case when viewed linearly from surface towards core	Case depth, inch.
Charcoal	Normal	925°C	2½	4	8	0.35	0.0035	5	0.0175
Charcoal	Sealed	"	"	3	4	0.50	0.005	6	0.030
Conventional carburizing mixture	Normal	"	"	3	4	0.50	0.005	8	0.040
Conventional carburizing mixture	Sealed	"	"	3	4	0.50	0.005	11	0.055
Titas Gas	Normal	"	"	3	4	0.50	0.005	13	0.065

CHART NO. 3

Medium of carburization	Volume of three one inch cube steel specimens to be carburized, cubic inch.	Case depth desired in inch.	Holding temperature, C.	Quantity of carburizing medium required.	Cost in Taka.
Titas Gas	3	$\frac{1}{20}$	925	4 cft	0.03*
Carburizing mixture	3	$\frac{1}{20}$	925	1.5 lb.	5.00

* For Industry:

Price of 1000 cft. Titas Gas is Tk. 7.20.



(a)



(b)

Fig. 18 Microstructure of the steel specimens carburized

(a) at 850°C for $1\frac{1}{2}$ hours.

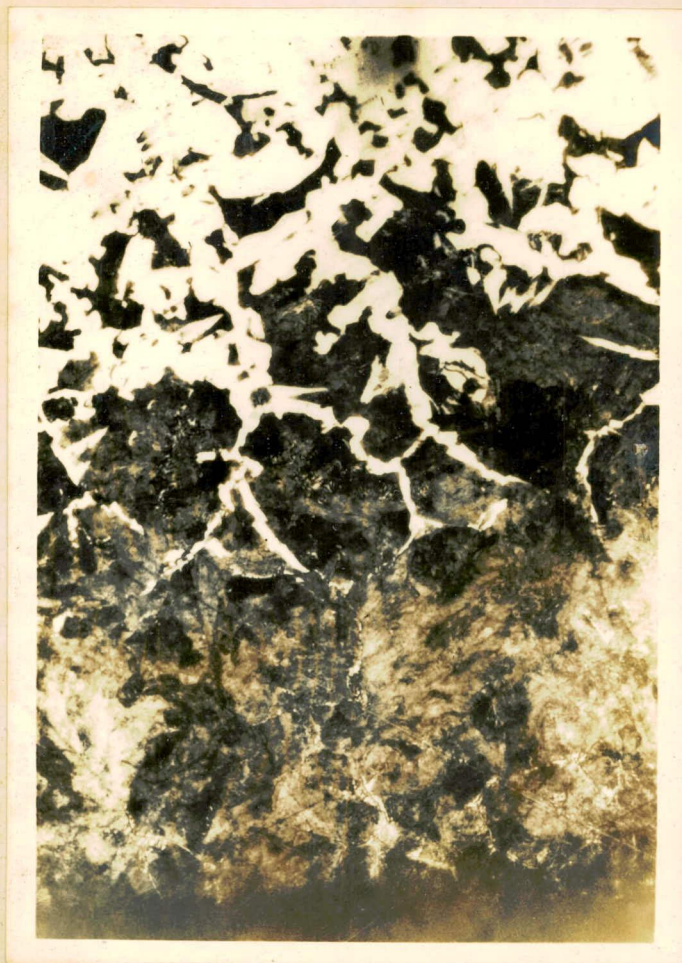
(b) at 850°C for 2 hours.

(c) at 850°C for $2\frac{1}{2}$ hours.

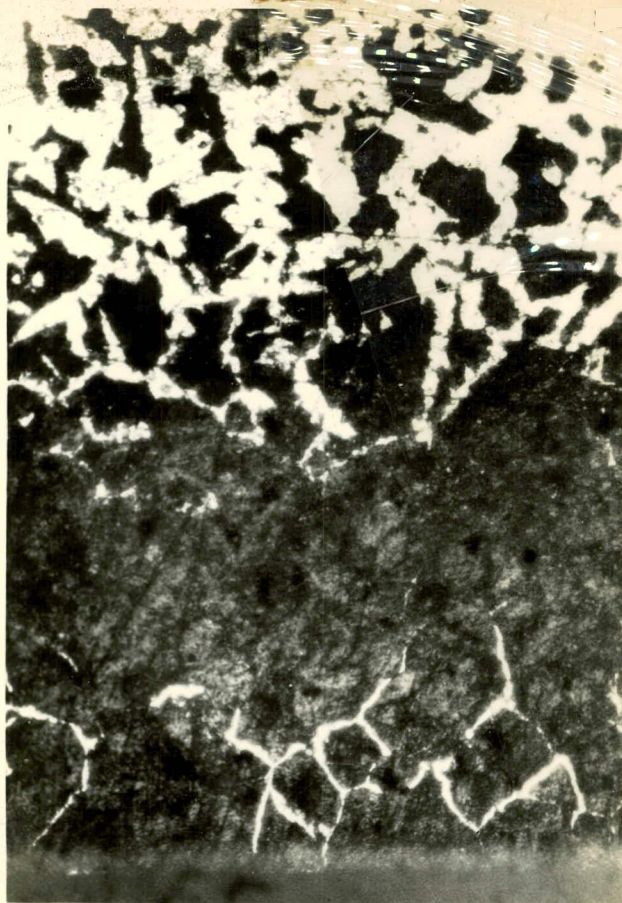
(150 X)

High-carbon case at the bottom;

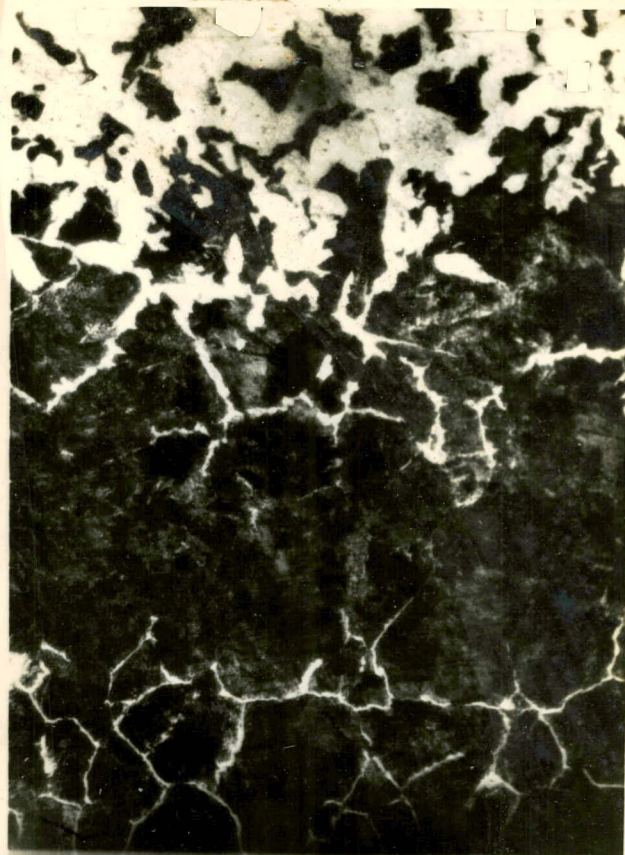
Low-carbon core at the top.



(c)

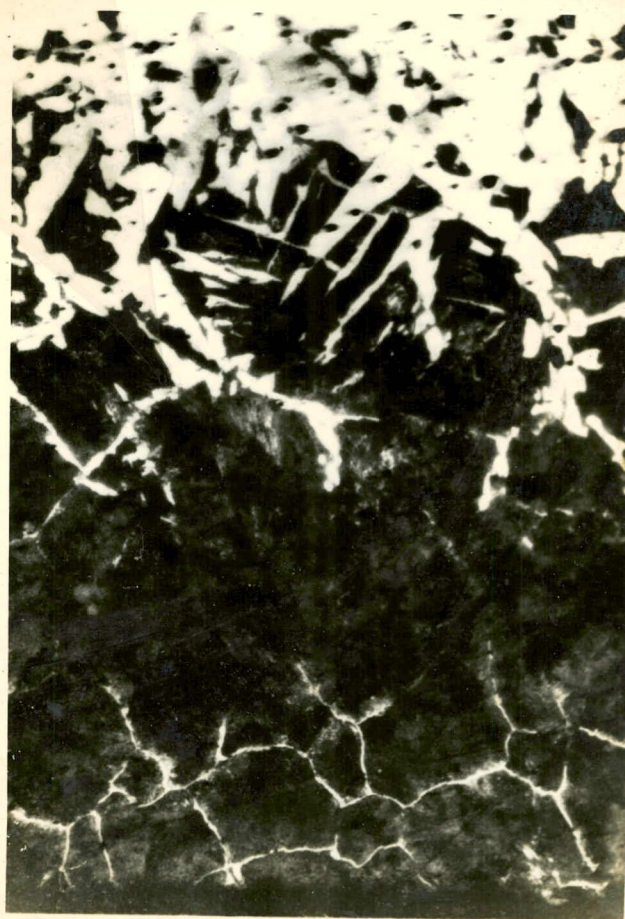


(a)

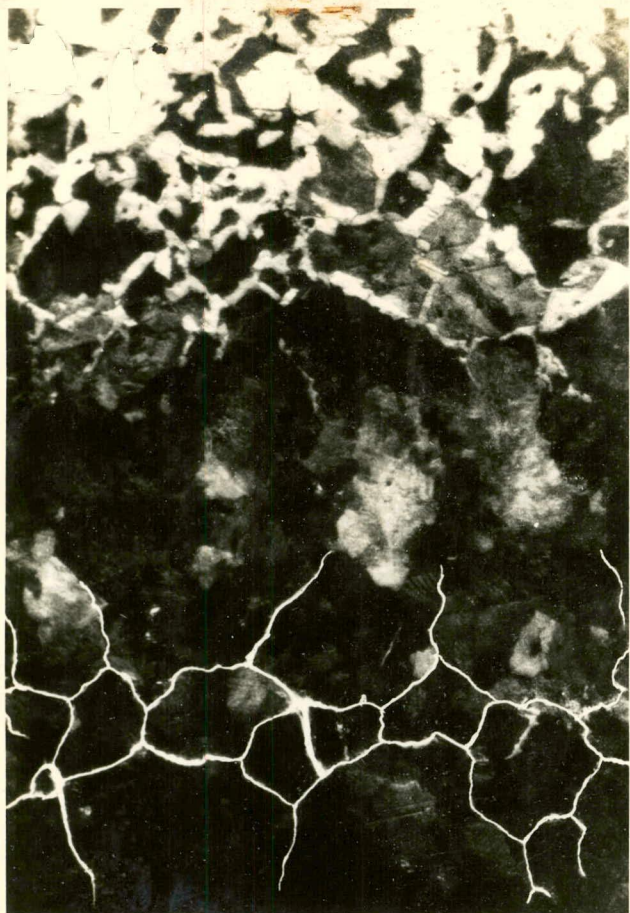


(b)

Fig. 19 Microstructure of the steel specimens carburized
(a) at 875°C for $1\frac{1}{2}$ hours.
(b) at 875°C for 2 hours.
(c) at 875°C for $2\frac{1}{2}$ hours.
High-carbon case at the bottom;
Low-carbon core at the top.



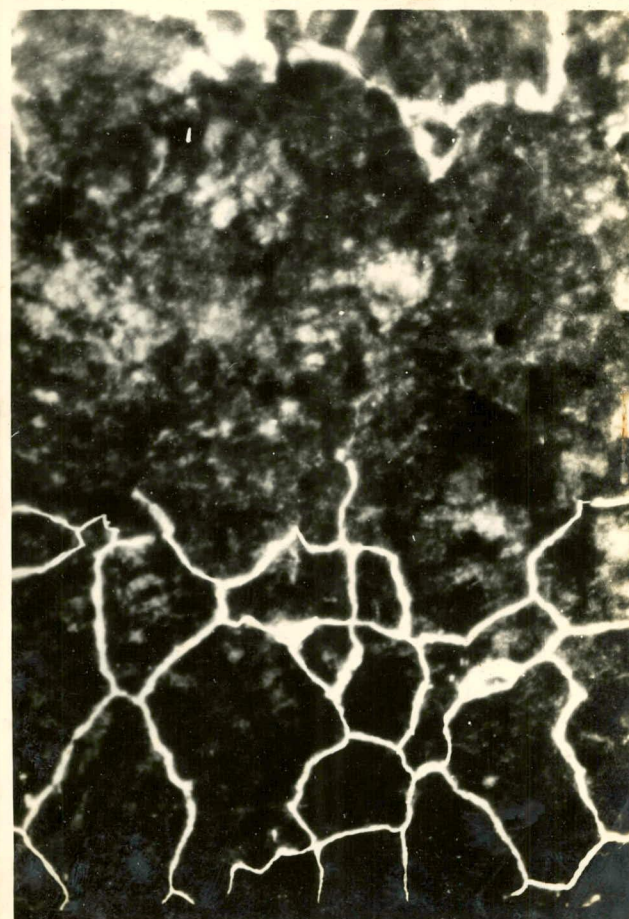
(c)



(a)



(b)



(c)

Fig.No.20 Microstructure of
the steel specimens carburized

(a) at 900°C for $1\frac{1}{2}$ hours.

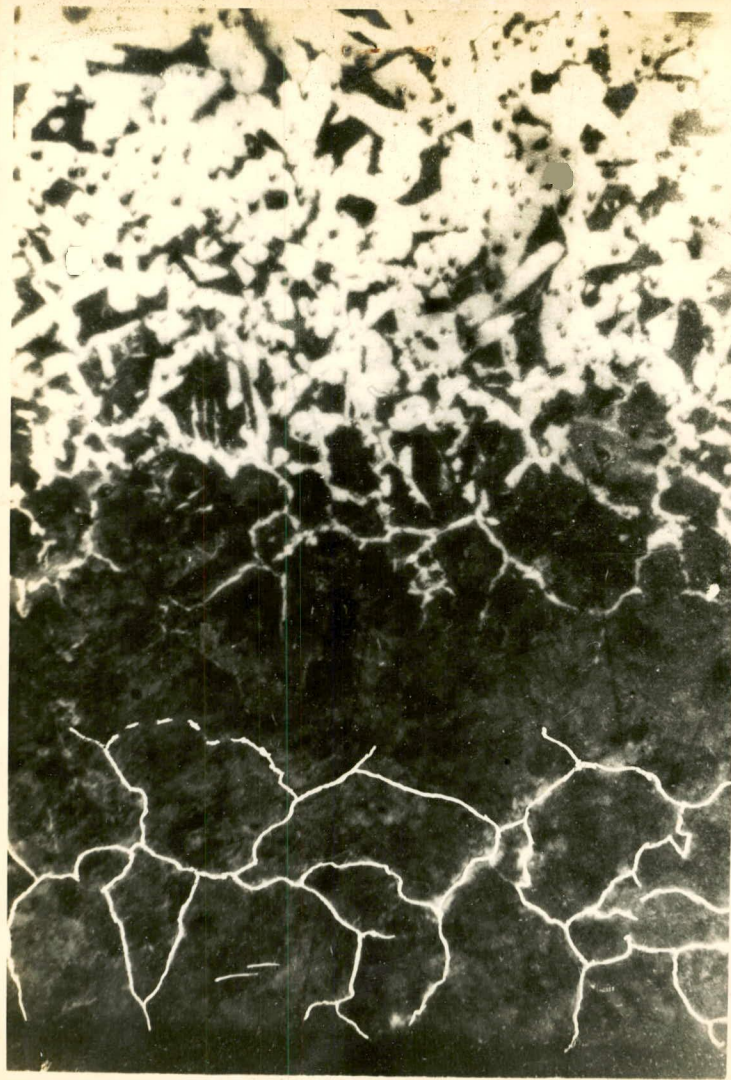
(b) at 900°C for 2 hours.

(c) at 900°C for $2\frac{1}{2}$ hours.

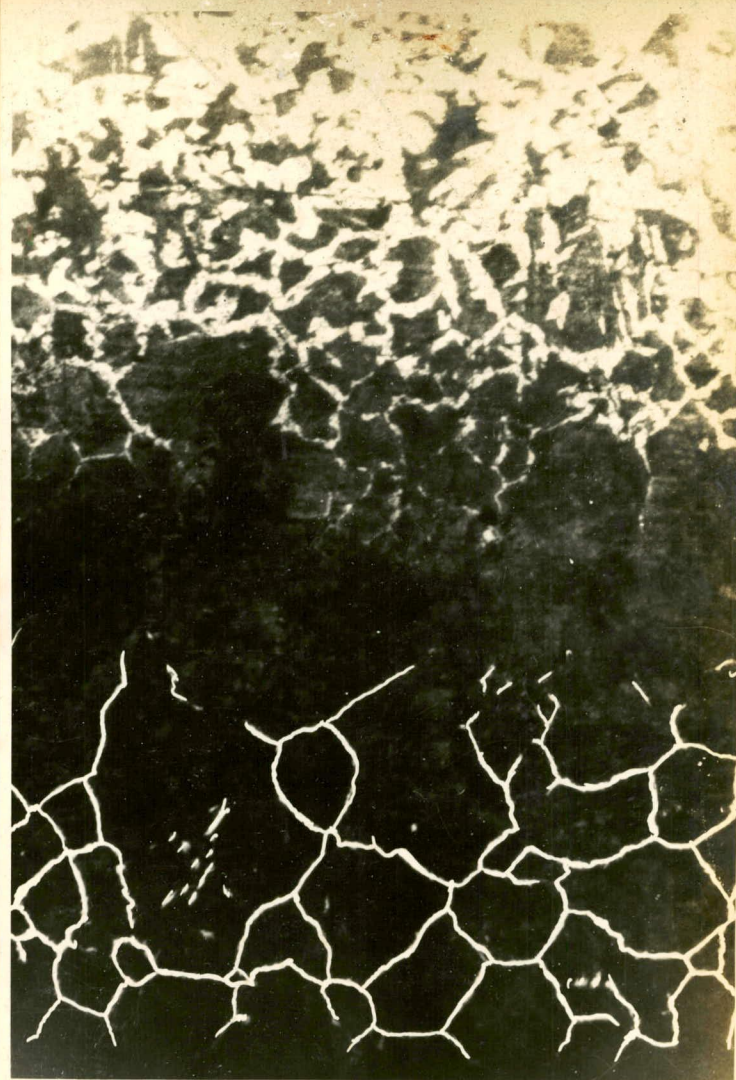
(150 X)

High-carbon case at the bottom;

Low-carbon core at the top.



(a)

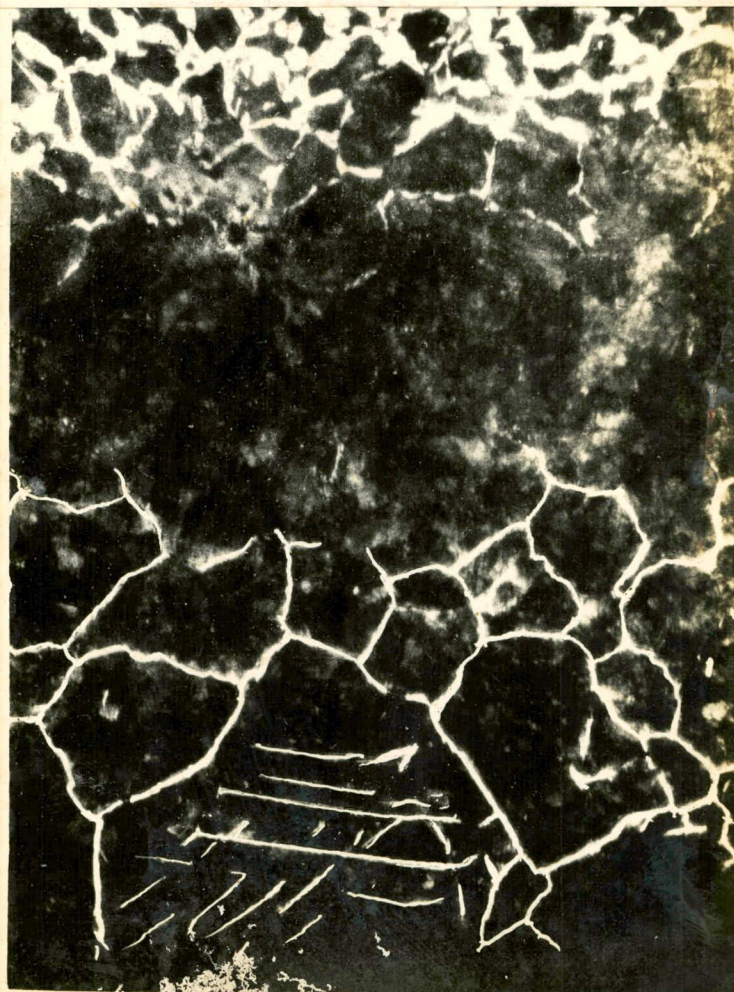


(b)

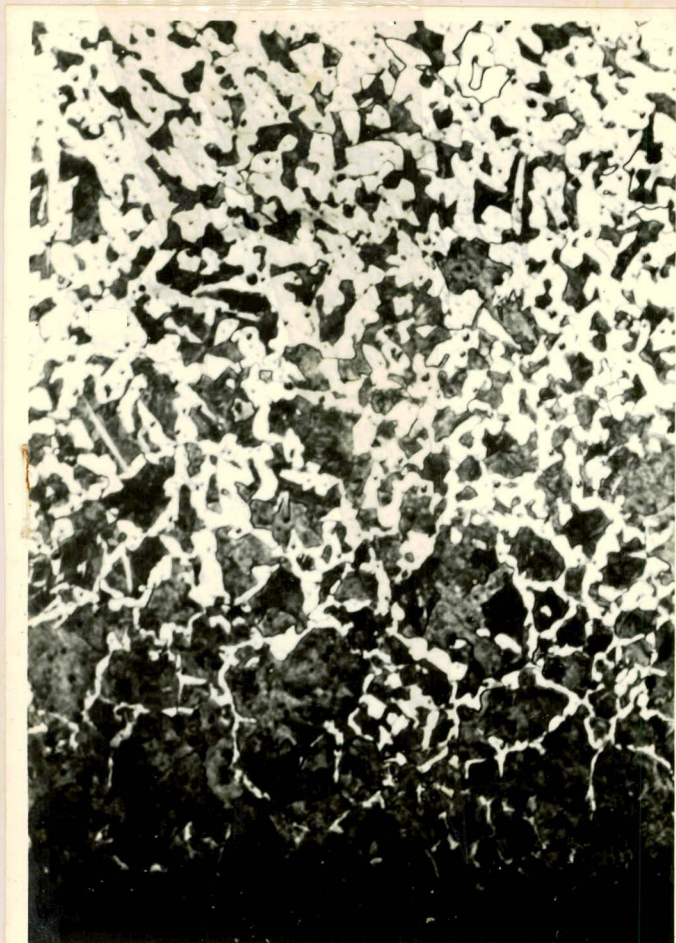
Fig.No.21 Microstructure of
the steel specimens carburized
(a) at 925°C for $1\frac{1}{2}$ hours.
(b) at 925°C for 2 hours.
(c) at 925°C for $2\frac{1}{2}$ hours.

(100 X)

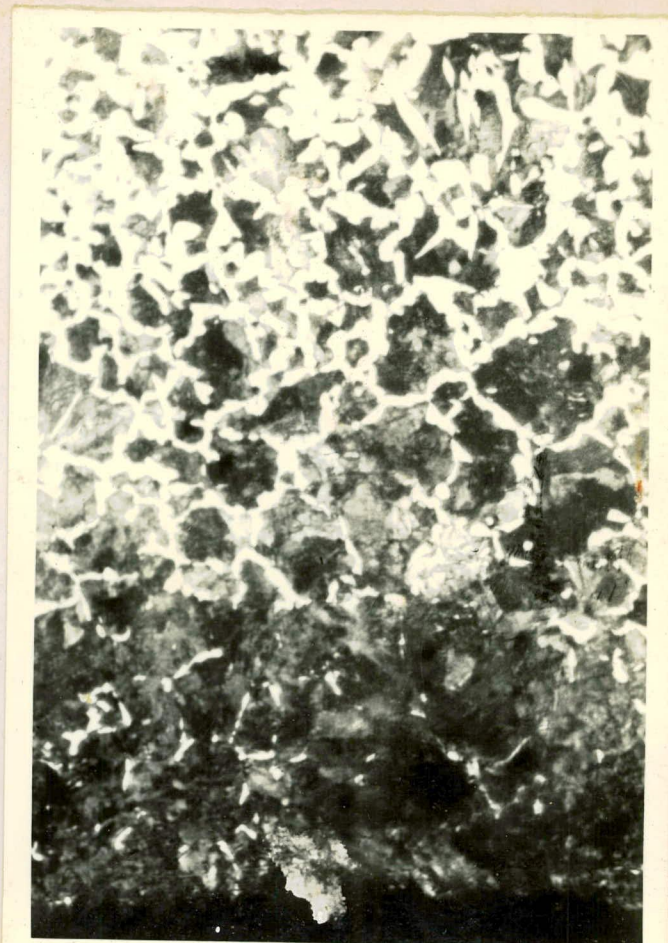
High-carbon case at the bottom;
Low-carbon core at the top.



(c)



(a)



(b)

Fig.No.23 Microstructure of the steel shaft carburized
at 925°C for 2½ hours with solid carbon (charcoal)

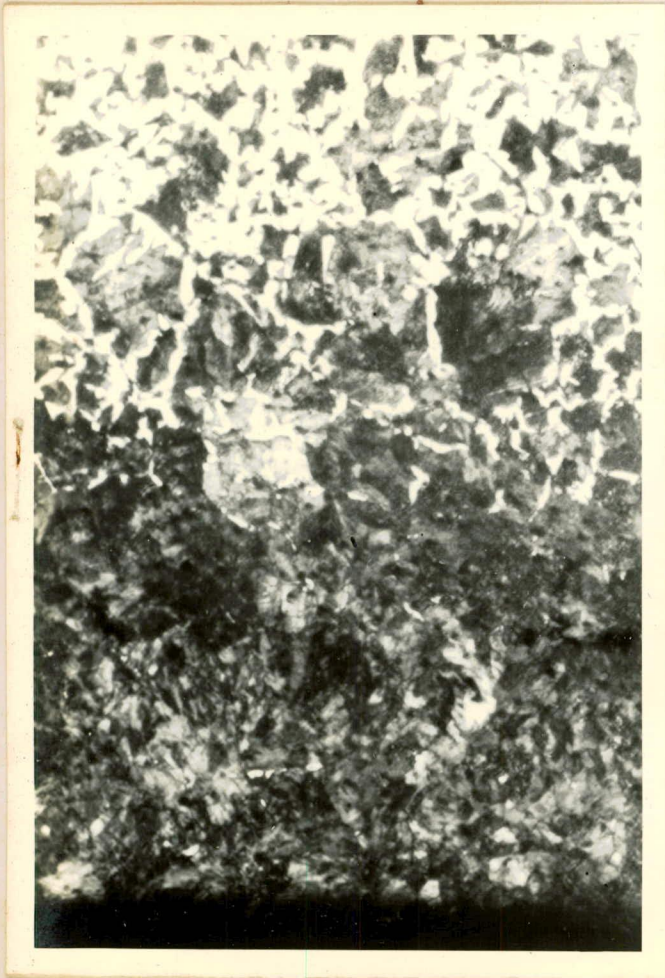
(a) Packing - Normal

(b) Packing - Sealed

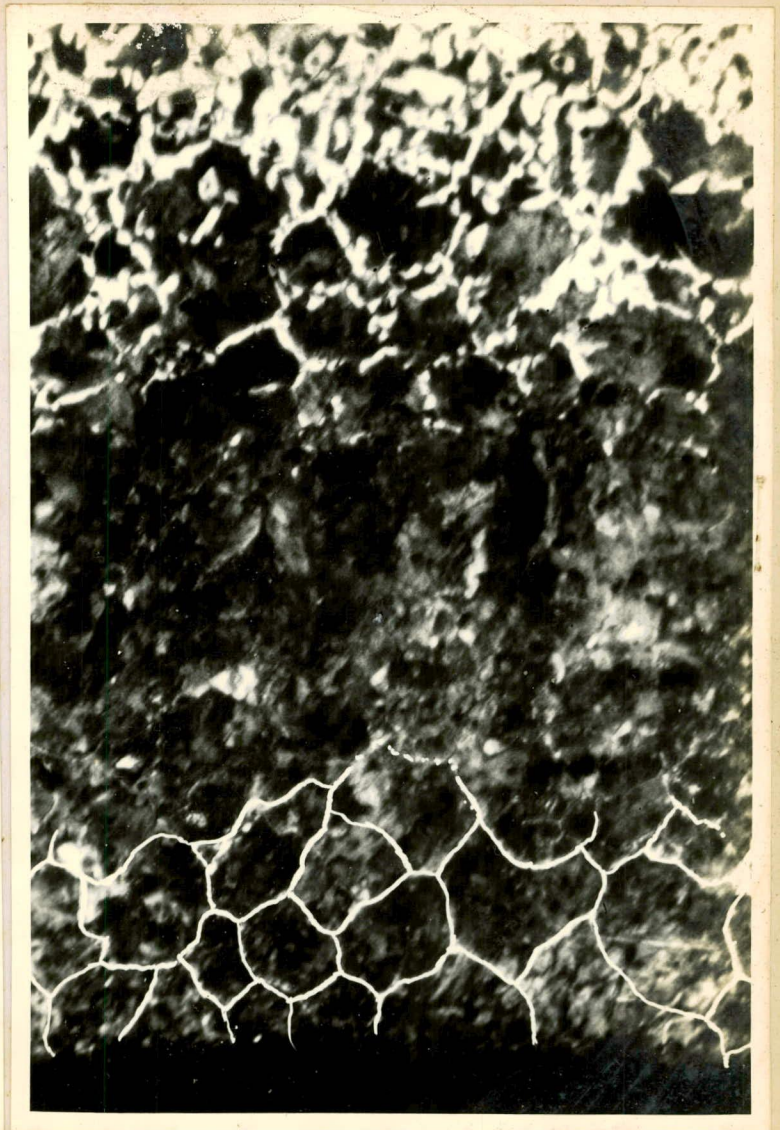
(100 X)

High-carbon case at the bottom;

Low-carbon core at the top.



(a)



(b)

Fig.No.24 Microstructure of the steel shaft carburized at 925°C for $2\frac{1}{4}$ hours with conventional carburized mixture

(a) Packing - Normal

(b) Packing - Sealed

(100 X)

High-carbon case at the bottom;

Low-carbon core at the top.

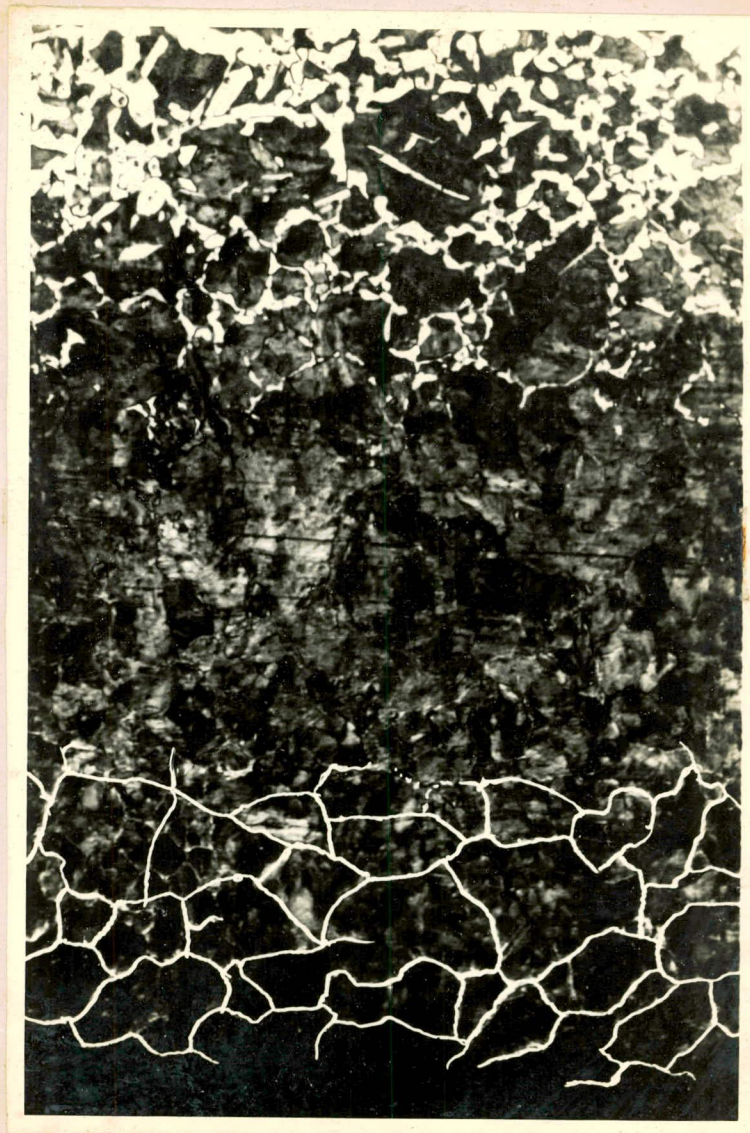


Fig.No.25 Microstructure of the steel shaft carburized
at 925°C for $2\frac{1}{2}$ hours with Titas Gas. (100 X)
High-carbon case at the bottom;
Low-carbon core at the top.

CHAPTER - V

CONCLUSION

CONCLUSION

Finally the following informations may be summerised from the experiments performed under this project:

The Titas Gas can be successfully utilized in carburizing the low carbon steel parts used as a tool or important machine parts to resist wear and tear during the service.

The experiments also prove that so long other factors remain constant the rate of carburization is more compared to other methods of carburization namely conventional pack carburizing mixture and solid carbon. Chart No. 2 shows that under identical conditions carburization by Titas Gas is about 62% and 270% more than carburizing mixture and solid carbon respectively.

Chart No. 1, Microstructure of Fig. Nos. 18 to 21 and Graph of Fig. No. 17 show that the extent of carburization is a function of time and temperature i.e. higher the temperature and longer the carburizing period, the greater will be the case depth. Also the rate of carburization is more at elevated temperature while the same is low at lower temperature as evident from graph of Fig. No. 17.

Chart No. 2 also reveals that carburization is also a function of pressure of its medium. Microstructure of Fig. 23(b) and Fig. 24(b) shows greater extent of carburization at higher pressure obtained by plugging the bores containing the solid carbon and carburizing mixture as compared to normal packing one Fig. 23(a) and 24(a) under same environment of time and temperature.

Some experiments also revealed that carburization is more in a clean gaseous atmosphere compared to the condition where some gas has been cracked giving rise to the formation of soot deposit.

Chart No. 3 shows that carburization by Titas Gas is cheaper than Pack carburizing mixture or any other medium. About 4 cft. of Titas Gas is sufficient to carburize three steel specimens of one inch cube to a depth of $1/20$ " at temperature of 925°C while about 1.5 lb of carburizing mixture will be required to carburize the same volume of specimens to the same extent at the same temperature. The cost of 4 cft. Titas Gas is negligible as compared to the carburizing mixture. Moreover some of the ingredients of the carburizing mixture, such as sized coke, Barium carbonate, Calcium carbonate, Sodium carbonate etc. are imported from abroad at high cost and thus required foreign exchange. Besides, the preparation of judicious carburizing mixture is a skilled job and is time consuming.

It was also observed that carburization by Titas Gas will have a higher production capacity because of shorter carburizing time.

Experiments also show that uniform case depth can be obtained by the gas compared to that by carburizing mixture.

Complicated machine parts can easily be carburized by the gas.

Considering the above mentioned facts, the Titas Gas is hereby recommended to be used as a carburizing medium for surface hardening of low carbon steel parts. Any industrial concern where Titas Gas has not yet been supplied may procure high pressure gas cylinder and can use the gas in case carburizing the steel parts.

Since the experiments under this project proved that the carburization by natural gas (Titas Gas) has been successfully carried on, some actual work of low carbon mild steel shafts supplied by some outside party has been very satisfactorily carburized by this method in this department. Recently the demonstration of carburization to the departmental students is being carried on by this method.

The work so far carried under this project suggests few more investigations to be followed:

- (1) Analysis of the gas leaving the carburizing chamber.
 - (2) Volume of the gas required for heating the carburizing chamber.
- This will provide an overall economic aspect of the whole project.

(3) During experiment heavy soot deposition was observed in some cases. Some experiments may be conducted to find the optimum temperature of cracking the Titas Gas so that cracked gas product i.e. soot may be used as an ingredient in the manufacture of black paint, shoe polish, coating materials, etc.

BIBLIOGRAPHY

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1. Leslie Aitchison, A History of Metals, Vol. 1, Macdonald and Evans Ltd., London 1960, p. 112.
2. Robert B. Leighou, Chemistry of Engineering Materials, Fourth Edition, McGraw Hill Book Company, Inc., New York and London, 1942, p. 340.
3. Seminar, 1972, Department of Chemical Engineering, BUET, Dacca, Natural Resources and Industrial Prospects in Bangladesh, P.B-2.
4. Metal Handbook, 1948 Edition, The American Society for Metals, P.678.
5. Van Vlack, Elements of Material Science, Second Edition, Addison-Wesley Publishing Company, Inc. London, 1964, P.86, P.87, P.89, P.97, P.100-P.103 & P.389.
6. Albert G. Guy, Elements of Physical Metallurgy, Second Edition, Oxford & IBH Publishing Co., New Delhi, 1967, P.406, P.407.
7. Metal Handbook, 8th Edition, Vol.2, 1971, American Society for Metals, P. 98.
8. Clark and Varney, Physical Metallurgy for Engineers, 2nd Edition, D. Van Nostrand Company, Inc., New York and London, 1962, P.150, P.253, P. 255.
9. Ernest J. Teichert, Metallography and Heat Treatment of Steel, Volume III, Second Edition McGraw-Hill Book Company, Inc., New York and London, 1944, P. 343, P. 345.
10. Metal Hand book, 1948 Edition, The American Society for Metal, P. 680 and Robert B. Leighou, Chemistry of Engineering Materials, Fourth Edition, New York and London, McGraw Hill Book Company, Inc., 1942, P. 342 and P. 345.
11. Technical Data - Atlas tool steels, Atlas Steels Ltd. Canada, P.7.
12. Harry, L. Campbell, The Working, Heat-Treating and Welding of Steel, Second Edition, John Wilay and Sons, Inc., 1948, P.66 & P.67.

RADIO-BOND

APPENDIXES

RADIO-BOND R

MADE IN AUSTRIA

MADE IN AUSTRIA

APPENDIX-ACalculation to find the extent of carburization i.e. case depthCase depth for Expt. No.1

Temp. 850°C; Time 1½ hrs.

In Expt. No. 1 the carburized portion of the steel specimen upto 0.6% carbon showed average grain size No.3 at 100X.

Now from ASTM grain size chart Fig. No. 16 and grain size table 1,

1 in.² at 100X contains 4 grains on average

4 in.² " " " 16 " " "

or 2" length at 100X contains $\sqrt{16} = 4$ grains on average

∴ 4 grains at 100X occupy a length of 2"

1 grain at 100X " " " " $\frac{2}{4} = 0.50$ "

1 grain at normal size " " " 0.005"

Now total number of grains in the carburized case of the specimen when viewed linearly through the microscope = 4

∴ the required case depth = $0.005 \times 4 = 0.020$ "

Case depth for Expt. No.5

Temp. 875°C; time 2 hrs.

In Expt. No.5 the carburized portion of the steel specimen upto 0.6% carbon showed average grain size number 4 at 100X.

Now from ASTM grain size chart of Fig. No.16 and ASTM grain size table 1,

1 in.² at 100X contains 8 grains on average

4 in.² at 100X contains $4 \times 8 = 32$ grains on average

or 2" length at 100X contains $\sqrt{32} = 5.68$ grains on average.

∴ 5.68 grains at 100X occupy 2" length

1 grain at 100X occupy $\frac{2}{5.68} = 0.35"$

1 grain at normal size occupy 0.0035"

Now total no. of grains on the carburized case of the specimen when viewed linearly through microscope = 8

∴ the required case depth = $0.0035 \times 8 = 0.028"$

Case depth for Expt. No.12

Temp. 925°C; time 2½ hrs.

In Expt. No.12 the carburized portion of the steel specimen upto 0.6% carbon showed average grain size number 2 at 100X

Now from ASTM grain size chart of Fig. No.16 and grain size table 1,

1 in.² at 100X contains 2 grains on average

4 in.² at 100X contains 8 grains on average

or 2" length at 100X contains $\sqrt{8} = 2.84$ grains on average

∴ 2.84 grains at 100X occupy a length of 2"

1 grain at 100X occupy a length of $\frac{2}{2.84} = 0.70"$

1 grain at normal size " " " 0.0070"

Now total no. of grains on the carburized case of the specimen when viewed linearly through microscope = 9

∴ the required case depth = $0.0070" \times 9 = 0.063"$

APPENDIX-BCalculation for Chart No.3

Volume of gas and carburizing mixture required to carburize three one inch cube steel specimens separately:

- (A) Flowrator Meter reading is 3, Temperature 36°F & pressure - one atmosphere.

The ratormeter reading 3 represents the volume of air of 1650 cc/min. at 14.7 psia and 70°F .

Since the density of air and that of Titas Gas which is predominantly Methane may be considered to be 2:1 at 86°F ,

$$\begin{aligned}\therefore \text{Volume of gas at one atmosphere and } 86^{\circ}\text{F} &= 825 \text{ cc/min.} \\ &= \frac{825}{(2.54 \times 12)^3} \text{ cft/min.} \\ &= 0.029 \text{ cft/min.}\end{aligned}$$

Now $2\frac{1}{4}$ hours total carburizing time including half an hour heating and $\frac{1}{4}$ hours holding time is needed to produce a case depth of $\frac{1}{20}$ " at 925°C (Chart No.1).

$$\therefore \text{Total gas supplied for } 2\frac{1}{4} \text{ hours} = 0.029 \times 135 = 3.91 \approx 4 \text{ cft.}$$

- (B) Let us now calculate how much conventional carburizing mixture will be required to carburize these three steel specimens to the same extent of case depth.

Generally in pack carburization, the desired steel specimens are packed with the carburizing mixture maintaining uniform thickness of the mixture of about $\frac{1}{2}$ " on all sides of the specimens. A steel box of

2 square inch in cross-section and 5" in height will be sufficient to hold these three specimens in a medium of carburizing mixture.

$$\begin{aligned}
 \therefore \text{Volume of carburizing mixture} &= \text{Volume of the box} - \text{volume of specimens.} \\
 &= [(2 \times 2 \times 5) - 3] \text{ cubic inch} \\
 &= (20 - 3) \text{ cubic inch} \\
 &= 17 \text{ cubic inch} \\
 &= 0.01 \text{ cft.}
 \end{aligned}$$

Now specific gravity of the carburizing mixture may be calculated as follows:

<u>Name of the ingredient</u>	<u>Composition</u>	<u>Sp. gr.</u>
Activated charcoal	55 parts	$0.55 \times 2.2 = 1.210$
Sized coke	30 parts	$0.30 \times 1.8 = 0.540$
Barium carbonate	10 parts	$0.10 \times 4.3 = 0.430$
Calcium carbonate	3 parts	$0.03 \times 2.7 = 0.081$
Sodium carbonate	2 parts	$0.02 \times 2.3 = 0.046$

$$\therefore \text{Sp. gr. of the mixture} = 2.307$$

$$\therefore \text{Weight of the reqd. carburizing mixture} = 2.307 \times 62.4 \times 0.01 = 1.5 \text{ lb.}$$

$$\text{Weight of activated charcoal} = 1.5 \times 0.55 = 0.825 \text{ lbs.}$$

$$\text{" " sized coke} = 1.5 \times 0.30 = 0.450 \text{ "}$$

$$\text{" " Barium carbonate} = 1.5 \times 0.10 = 0.150 \text{ "}$$

$$\text{" " Calcium carbonate} = 1.5 \times 0.03 = 0.045 \text{ "}$$

$$\text{" " Sodium carbonate} = 1.5 \times 0.02 = 0.030 \text{ "}$$

Now cost of 0.825 lbs. activated charcoal	= 0.825x1.00 = Tk.0.825
" of 0.450 lb sized coke	= 0.450x1.00 = Tk. 0.450
" of 0.150 lb Barium carbonate	= 0.150x25.00 = Tk. 3.250
" of 0.045 lb calcium carbonate	= 0.045x0.25 = Tk.0.036
" of 0.030 lb Sodium carbonate	= 0.030x5.00 = Tk. 0.150

∴ Total cost of the mixture = Tk. 4.71
= Tk. 5.00

