Paper No. 163

Mix-Ratio Analysis Method

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IMPROVED CAST IRONS IN THE SERVICE OF ENGINEERS

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SYNOPSIS

It is the aim of this paper to review developments taking place in recent years for modification and strengthening of cast iron which historically was known to be rather weak material. The cause of weakness of grey iron as structural material has generally been the presence of graphite in the form of flakes which are brittle and their edges constitute sharp int-ernal notches. By carefully controlling the shape and form of amorphous graphite, major improvements in the properties of Cast Irons have been made. The casting now made in the form of ductile irons have a major impact on aut–omotive industry and more than half of the steel castings and steel forgings have been replaced by such improved cast irons. Their performance and reliability by any yardstick has been superior performance and reliability by any yardstick has been superior to the steel components they replaced. Advancements in cast iron technology provide vast oppertunities for development of such products. Such opportunities were never possible with traditional grey iron and even many cases with steel such as crankshafts, connecting rods, Cam shafts, rear axle, rocker-arms, followerarms and steering knuckes for disc brakes etc. The technology requires properly equipped laboratories and experienced competent technical personnel for constant quality control and checks. In Pakistan a lead can be given in the public sector by heavy forge and foundry, Karachi Shipyard, millet Tractors, PECO, heavy machanical complex etc. by a conscious joint planning efforts to usher in a new era of industrilization and development.

Introduction

Until just a few decades, cast iron was almost universally considered as a cheap brittle material possessing little strength in tension or shear and practivally no ducility. Cast iron was also considered as being rather undependable because its properties varied so widely from casting to casting as these were incapable of modification by any kind of treatment after sobidification. Within recent years, however changing economic conditions have caused a wide spread search for cheeper enginnering materials of good physical properties and consequently by the internal structure and constitution of cast iron, as well as the methods of producing it have been intensively studied particaularly influence of trace elements on graphite flakes by the matallurgists all over the world with surprisingly good results. Before proceding further, it may be well to understand exactly the plain gray cast iron with reference to flake types and flakes sizes according to joint recommendations of AFA and ASTM. As regard graphite flakes types in gray cast iron, there are five types:-

Type A-uniform distribution, random orientation, Type B-rosettce grouping, randomly oriented; Thpe C- superimposed different flake size, random orientations; Type D- inter-dendritic flakes. random orientatioin; Type E- inter-dendritic flakes, prefered orientation. Their sizes at x100 magnificatiion are from 4 inches to less then 1/16 inch in length. Fig 1 and Fig 2 show types of graphite flake and their respectively. In addition to the types of graphite flakes and their sizes, the form of graphite has great influence on the strength of cast iron. Most common graphite forms are flaky, craby, nodular and vermicular, Flaky Form:– The flakes in any form and length are brittle and disrupt continuity of the matrix and their edges constitute sharp internal notches, which become the cause of low tensile strength of the cast iron as compared with steel. Complex demands for the effective use of cast irons calling for strength toughness elasticity, wear resistance and at the same time good holding and sliding characteristic are based onthe types of graphite flakes. Types D and E flaakes are most undesireable. These are very fine Lacy and frequently occur in an interdendritic pattern. These flakes are usually surrounded by ferrite areas. Types A and B are usually more desireable graphite flakes structures which is mostly achieved by inoculation of the superheated iron i.e. above 1450^{o}c. Super-heating without inoculation induces greater under cooling and as a result get ferrite associated with under-cooled graphite which is undesireable structure. Most of the castings of spare parts of diesel engines and auto engines have A and B Type graphite flakes in pearlitic matrix.

Castings of spare parts of automaotives and tractors

Two types of castings are involved for the production of automotive and tractor components; castings of thicker sections where soundness and pressure tightness are important and castings of their sections calling for stregth, toughness, elasticity and wear resistance. Casting of thicker include the flywheel, crankshaft, crankcase, pistons, liners, eylinder head, water Jacket and gear wheels. The ultimate tensile strength of these castings is between 18 and 20 tons per sq in photo-micregraphs of these castings and given at fig 4 and 5 to give clear conceptiion of graphite flakes essentially required to have the quality of the product competitive with the international standard.

Combustion Chamber Parts

Combustion chambers parts are subject to side range of arduous conditions than any other part of an engine and upon their reliabilitythe success of an engine largely depends. Requirements depending upon the working condition of each part are varying combinations of high strength, fatigue, shock and wear resistance, structural resistance to thermal stress etc and most of them have A type graphite flakes in pearlitic matrix.

Cylinder Head

Higher strength iron is necessary for the cylinder head and inoculated nickel/chromium iron having as total carbon of about 3.2 percent is being used. Micro-structure is fully pearlitic having 3. tensible strength of 21. 8 tons per Sq in.

Liners

Considering combustion chamber castings. The liner is generally the simplest in form. Liners must obviously have good gear resistance and sliding properties, relatively good corrosion and fatigue characteristics and structural thermal slability. Centrifugal casting is attractive as a production process but it imposes metallurgical limitations not in common with sand castings. Large number of smaller liners are centrifugally cast but most of them have undue undercooling of the graphite accompanied by excessive amounts of free ferrite which makes them susceptical for rapid wearing. However high allowances are kept on the inner and outer surfaces to have suitable quality graphite flakes in the region of bore.

The graphite form and amount is a major factor and experience has shown that between about 2.4 t o 2.7 percent occuring as short 'Chunky' flakes randomly distributed give good results under most service conditions. The propert ies of the pearlitic matrix are also important and alloy additions are made to increase its strength toughness, hardness, thermal stability, resistance to scuffing, seizing and corrosion.

Pistons

Mostly pistons are made of aluminium alloys such as LM13 which is modified by sodium salts during the course of melting. Subsequently aluminium alloy pistons are given solution treatment and precipitation hardening treatment for thermal stability. However pistons of cast iron are also used having 15 tons per Sq in tensile strength in the ring grooves, with a total carbon content of about 3.2 percent.

Castings of their Sections

Piston Rings

Casting of piston rings is a typical example of thin section castings. Piston rings are hard working, ill used units and its demands are complex, calling for strength, thoughness, elasticity wear resistanc and at the same time good bedding and sliding characteristics.

They may be produced as separately cast items but are more usually turned from pots produced as centrifugal or sand castings. The outersurface of the centrifugally cast castings usually contain very fine under-cooled grapbite with which is associated varying amounts of free ferrite or at the other end extreme and massice columner carbides.

Craby Form

Initial efforts to convert flakes of graphite to nodular form were the processes of "white heart and black heart" which involved time consuming treatment of hypo-entectic cast iron produce graphite aggregate nodules. Such irons were known as malleable cast irons which were produced by the prolonged annealing of white irons. The graphite formed by the Fe 3C – 3Fe + graphite with no flakes present, grows in all directions thereby forming as crab type nodule. Such nodules disrupt the ferrite much less and greatly dimish the internal notch effect and therefore show some ductility.

Connecting Rods

Connecting rods were made in malleable cast irons, before a method for the production of noduler graphite structure without applying heat-treatment was developed. The connecting rods were made in white-heart malleable having a composition as cast of C 3.2, Si O.35, Mn 0.15 and P o.06 percent. The annealing cycle for malleable castings consisted of heating period of about 24 Hrs. upto a temperatue of 1000^{o}c which was maintained for 120 Hors, the cooling taking about 30 Hours.

For the smallesection castings the silicon contect is raised to about 0.5 to 0.6 percent. Typical test results are tensile 22 to 24 tons per Sq in ellongation 7 to 10 %, Brinell hardness 120 to 140.

Nodular form or Spheroidal Form

The phenomenon of graphite precipitation in the nodular form or spheriodal form in cast irons is quite modern. Nodular cast irons may be defined cast irons having graphatic carbide in the form of nodules in a cast state without the necessity for heat treatment in order to achieve the structure.

Hypothesis pextaining to Nodular form of graphite:–

Graphite particles having different morphological forms require nuclei having different crystallographic structure. Cubic compounds such as magnesium carbide or magnesium silicate and other calcium, cerium and lithium compounds micliate spheroidal-from graphite, whereas hexagonal compounds such as silicon and silicates nucliate flake form graphite. According to the hypothesis relating graphite particles shape with a particular kind of mucleus, the addition of magnesum, calcium, cerium and lithium while destroying one kind of nucleus, promotes another. The author's view point with respect to spherodizing of graphite are as follows; austenite during the course of solidification get super-saturated with carbon on account of shifting of entectic point towards right under the influence of Nodoulising elements. The groups of carbon atoms at the faces of cubic crystaline formation starts moving towards the centre while conversion of f.c.c. crystaline structure transforms to B.C.C. crystaline structure. It causes the precipitation of entire carbon in the nodular form.

Method for the Production of Nodular form

The method for the production of nodular form involves in its simplest form the addition and solution of an appropriat amount sepherodizing agent to a molten cast iron of appropriate composition shertly before casting. The principal composition requirements for the production of nodular irons are given below:–

1- The iron must solidify gray even without the spheradising agents.

2- The iron must be hyper entectic carbon content.

3- Silicon content can have any value, but preferably within the range 2.3. to 5 percent.

4- Sulphur content of the metal to be treated should be as low as possibe, and after treatment should be about 0.015 percent.

5- Phosphorus content should not exceed about 0.6 per cent and should preferably be below 0.1 percent.

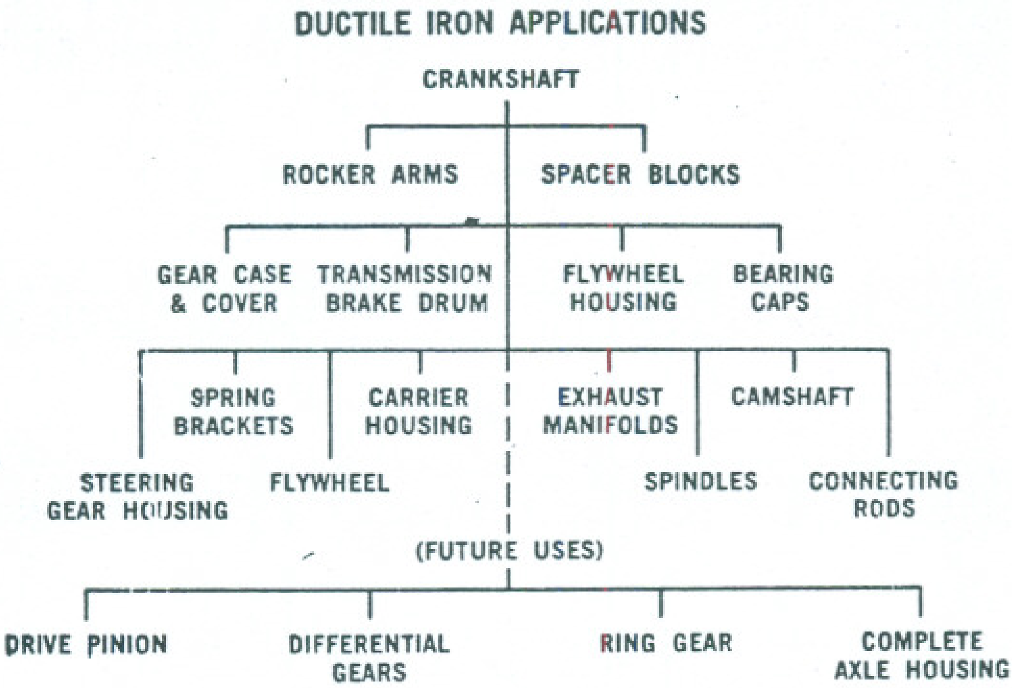
6- After tretment with magnesium the solidified castings must contain more then a certain munimum amount of 0.04 percent of the element dissoloed in the metallic matrix. Of the foregoing requirements the most important from the point of view of the successful use of the process are those covering the carbon and sulphuar contnets.

Ductile Irons application in Auto engines

Ductile cast irons have a major impacat on the automotive industry. As a result of graphite and spcaing, ductile iron is more resistanct to oxidation and oxidation growth than gray iron. At a temperature in 1200-1400 ^{O}F range, ductile iron is significantly strong than conventional gray irons.

A growth tree is presented toshow the more common applications in use today in Ammerica and elsewhere. Starting with crankshafts in 1951, the penetration od ductile iaron in the automobile industry is most impressive.

Growth Tree of Ductile Iron application in Auto engines is shown below:–



Auto-motice casting requirements represent approximately 53 per cent of the total world's advance countries, ductile iron casting production. The rapid growth of the ductile iron industry and the high annual application of ductile iron castings are testimonials to the outstanding mechanical properties, quality and economics of ductile iron castings. The fact that ductile iron castings are usedfor such critical automotive applications as crankshafts, front wheel spindle sports and connecting rod, is a further testimonial to the higher reliability and process economics associated with ductile iron castings.

The sudden arrival of spheroidal graphite cast iron on the materials scene more than 20 years ago, provide a cast iron with better properties than gray iron and better castability than steel. In time, engineers realized that it was not a single material with one set of properties but rather a family of materials with wide variety of properties, available at will and capable of serving a wide variety of engineering requirements. The soft ferritie grades are available to servewhen toughness and ductility are required and the harder pearlitie grades accommodate higher strength requirements. Grades with mixt-ures of pearlite and ferrite in the matrix serve a multit ude of variations of property demand in between. In addition heat treatments of various types present different and better combinations of propertites for applications with special requirements. Normalized pearlitec spheroidal graphite iron, for instance, substantially improves the strength ductility combination in comparison with as cast spheriodal graphite cast iron. Almost all the casted spare parts in automotive industry can easily be produced in nodular cast irons by having control on the form of nodular graphite and micro-constituents of the matrix and on the basis of them control on elengatiion can be exercised varying form 2 to 25%.

Crankshafts

The automotive crankshaft is considereed the "old reliable" ductile iron component. The first conversion from cast steel to ductile iron crankshafts began in 1951. The execllent field performance of the millions of ductile iron crankshafts used in automotive, Truck and Tractor service atleast to the outstanding mechanical properties and quality of pearlitic ductile iron castings. While steel forgings are still used for speical engine applications, with today's ductile iron technology most of the remaining forged steel crankshafts could be successfully converted to ductile iron.

Automotive crankshafts require a unique blend of machanical and physical properlies including torsional stiffness, fatigue strength, bearing surface finish and machinability. Typical materials that have been used for automot ive, truck and tractor crankshafts are malleable iron, ductile iron and forged steel.

Gray iron does not have the requiredstiffness or fatigue strength. Today, malleable iron crankshafts have been almost completaly converted to ductile iron as a result of lower manufacturing costs for ductile iron. Conversions of steel forgings to ductile iron cstings are continuing.

The dimensional accuracy of shell and current green sand molding technology is such that counter weight machining is no more required. The fact that machining is only required for functional surfaces such as bearings keyways. oil holes and attachment surfaces represents a major advantage of todays cast crankshafts, the bearing surface finish attained on pearlitic ductile iron is excellent.

Rocker Arms

Ductile iron rocker arms are produced using a shell mold, stack molding method, this casting process paroduces thin wall castings with good dimensional accuracy and low molding cost. The castings are heat-treated to break down any residual crabides and to fully ferritize the matrix, thus providing maximum casting ductility.

A key feature of the rocker arm application is utilization of the ability of ferritic ductile iron to be coined to final dimensions, thus minimizing costly machining operations. The only machining operation required is the drilling of one oil hole. The rocker arms are batch austanitized, oil quenched and tempered to provide the strength and wear resistance required for the final engine application.

Rear Axle

Rear axle carriers, gear cases and gear case covers are typical examples of as cast ferritie ductile iron casting appplacations. Requirements for these componets are good ductility, strength and shock resistance as well as excellent machinability.

Followers Arms

The ductile iron follower arms have successfully replaced forged steel which was subsequently, quenched and then hard chrome plated to resist excessive cam pad wear. The follower arm sits on a stud near one end and contacts the valve tip near the far end of its length. The camshaft rotates against a pad on the follower arm surface to control valve opening. The camshaft lobes are hardenable iron with a hardness of 50-60 Rockwell c. The follower arms require machiniability and excellent fat igue strength and wear resistance.

Exhaust Manifolds

Ductile iron has exeellent intermediate temperature (1200 to 1500°F) properties when compared with gray iron. Consequently ductile iron is an excellent exhaust mainfold material for severe duty applications. Advant ages of ductile-iron over gray iron for exhaust manifold application for hot enginees include:

Higher Transmission Tempearture

The typically higher silicon coupled with low manganese in ductile iron results in a higher transition temperature: the temperature at which austenite begins to form on heating.

Lower Oxidation and Oxidative Growth

Oxidation of cast iron proceeds most rapidly along the graphite matrix interfaces. In ductile iron the graphite is present as well dispersed spheres. In gray iron the graphite is present as flakes having sigh surface area.

Ductility: Ductile iron has the ability to plastically deform with thermal expansion and contraction under constrained condition. gray iron crackes.

Strength

Ductile irons are three to five times stronger than conventional gray irons in the 1200 to 1400 ^{O}F temperature range.

Ring and pinion Gears

Ductile iron gearing can be cast as a toothed blank significantly reducing the amount of materials to be removed during machining. Compared with forged steel practice, ductile iron offers the potential for major reduction machining costs.

To develop the necessary tooth strength and wear resistance ductile iron gearing is hardended after machining.

Quality Control for the Production of Ductile Irons

The raw materials of the foundry; pig iron, cast iron, scrap, steel scrap etc are not always simple. In additon to the major elements such as silicon, manganese, phosphorus and sulphur, small amounts of a wide variety of other elements are present in traces. For the production of normal flake graphite grey cast irons, these trace elements can be ignored. In case of nodular graphite irons, these trace elements have a profound effect on the fundamental object to produce nodular graphite structures and there-fore they should be avoided or limited to ineffective traces because they interfere with the production of nodular graphite. The elements lead, antimony, bismuth, tin, Arsenic aluminuim, titanium and copper are subversive elements and their effects on the form of graphite nodules, their structure and micro-constituents of the matrix are discussed in brief.

It has been found that small amounts of titanium lead, bismuth and antimony have pronounced subversive effect; tin in amounts upto .01 percent and arsenic, in amounts upto .04 percent can be tolerated without harmful effect on graphite formation; aluminium can also have a harmful effect, the harmful effect of copper has not been entirely confirmed but it has been found to be closely related to the subversive element content of iron. Each element is discussed to illustrate the subversive effect, on graphite formation, microscopy and mechanical properties.

Influence of lead:

Lead less than .006 percent has no harmful effect on U.T.S. elongation and Brinell hardness, but its further increase greatly influence the micrsoepic fongiruation of graphite, slight increase in percentage of lead content from .006 to .009 percent begins to have subversice effect. It's micrograph having small amount flake form of grphite is shown in figure 5. The occurance of this graphite is a ccompanied by a marked drop in elogation.

Influence of Bismuth

It has a harmful effect even in traces i.e. presence of 1 part of bismuth in 25,000 parts of iron influence elogation and U.T.S tremendously. Magnesium treated iron with .005 bismuth has flake form of graphite in a matrix of pearlite with little ferrite and occasional nodules. Bismuth in amounts of the order of .005 percent begins to have harmful effect and .006 percent bismuth can completely inhibit the nodular structure.

Influence of Antimony

Antimony has a harmful effect similar to that of lead and bismuth. A residual antimony content of only 0.004 percent of irontreated with magnesium has a profound effect on the elongation value. It has a small amount of flake graphite together with spherulitic noduls. Magnesium treated iron having 0.012 Sb has absolutely no elongation and therefore useless for the manufacture of spare parts.

Influence of Tin and Arsenic

For the production of soft iron of good ductibility, the Tin and Arsenic must be kept to a minimum. In the as cast condition or heat-treated irons, the presence of these elements can be tolerated upto 0.01 percent and .04 percent respectively. Magnesium treated iron having 3.69 percent carbon, 2% silicon, .009 % sulphur with 0.012 Tin has 15% elongation, same iron having 0.022 Tin has only 4% elongation. The drop in elongation with slight increase in percentage of Tin is most striking.

Influence of Aluminium

Aluminium inhibit the information of spherulitie nodules and cause the formation of flake graphite structure in magnesium treated iron. It does not effect elongation upto 0.1% but thereafter it reduces elongation however it affects adversely U.T.S. Magnesium treated irons having 0.34% aluminium contain flake graphite. Aluminium cause the retention of sulphur which in turn cause the formation of flake graphite, however it has been observed that aluminium has harmful effects even when sulphur contents are normal.

Influence of Titanuim

Titanium occurs more frequently in foundry Pig Irons in amounts capable of easy detection than any other subversive element. The influence of titanuim depends very considerably upon the magnesium content and the section size into which the metal is cast. Traces of a flake form can be seen in magnesium treated iron containing 0.04% titanium.

Influence of copper

The influence of copper in nodular cast irons depends very considerably upon the subversive elements content of the materials. The effect of copper on the formation of nodular graphite is not completely understood. Copper appears to make nodular cast iron more sensitive to the effect of subversive elements.

Vermicular form of graphite

Cast iron alloys containing vermicular form of graphite, with mechanical properties intermediate to gray and ductile iron, offer exciting possibilities to have potential in thin-wall casting application such as engine blocks with 0.09–0.120" walls and transmission cases. Transmission cases which have been fatigue tested showed a life of approximately 40,000 cycles in flaky graphite gray iron and 3,000,000 cycles with no failure in termediate strength iron. Fly-wheel subjected to spin test successfully passed the 15000 RPM test specified for ductile iron fly-wheels. Photo-micrograph of vermicular graphite is shown in figure 6.

Conclusion

The practices in the industrial world have undergone vast change and at present about 90% parts of automotives and tractors are manufactured out of gray cast iron and ductile iron castings. Pakistan can make use of these technological advances and all these Parts can similarly be manufactured within the country, High quality gray iron castings and ductile iron castings are produced by foundries of all sizes in America, Western countries and for Eastern countries. Trained man power, laboratory facilities, process control and attention to details can result in a successful quality control for the production of all types of Prime-movers within the country.

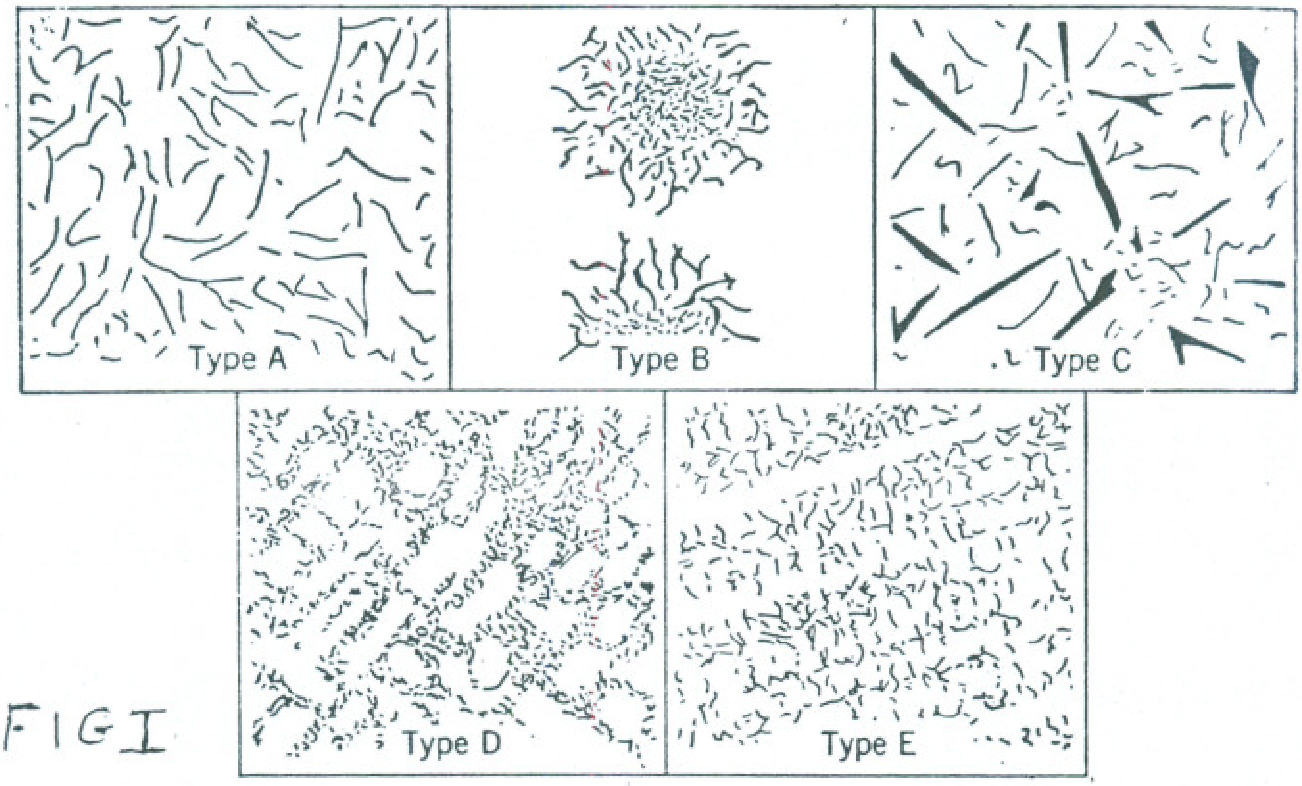
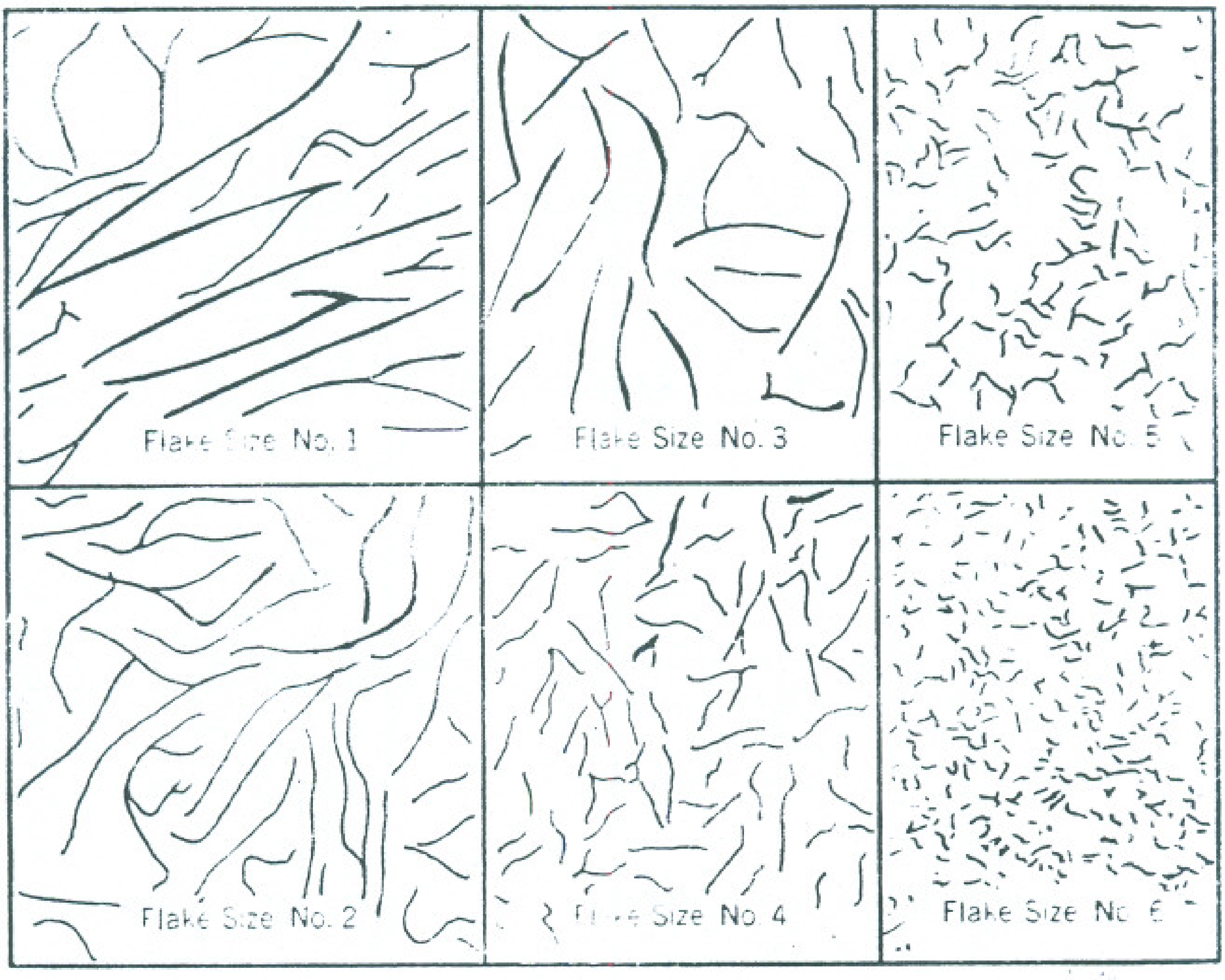


FIG I


Flake Size No. 1
Flake Size No. 3
Flake Size No. 5
Flake Size No. 2
Flake Size No. 4
Flake Size No. 6

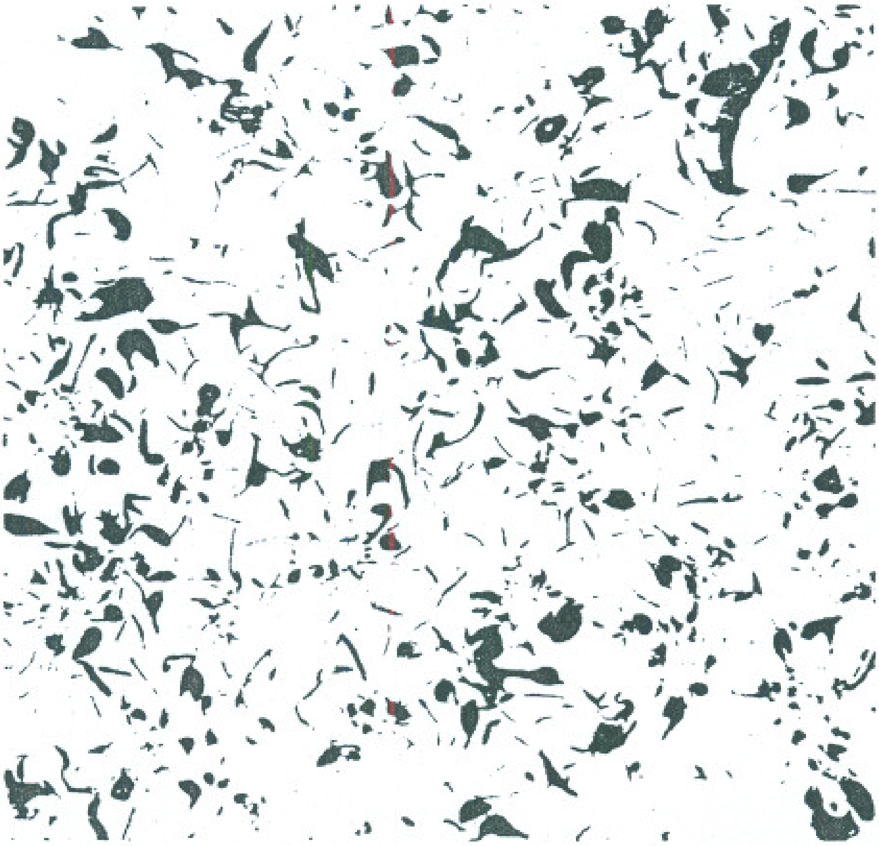


FIG 3

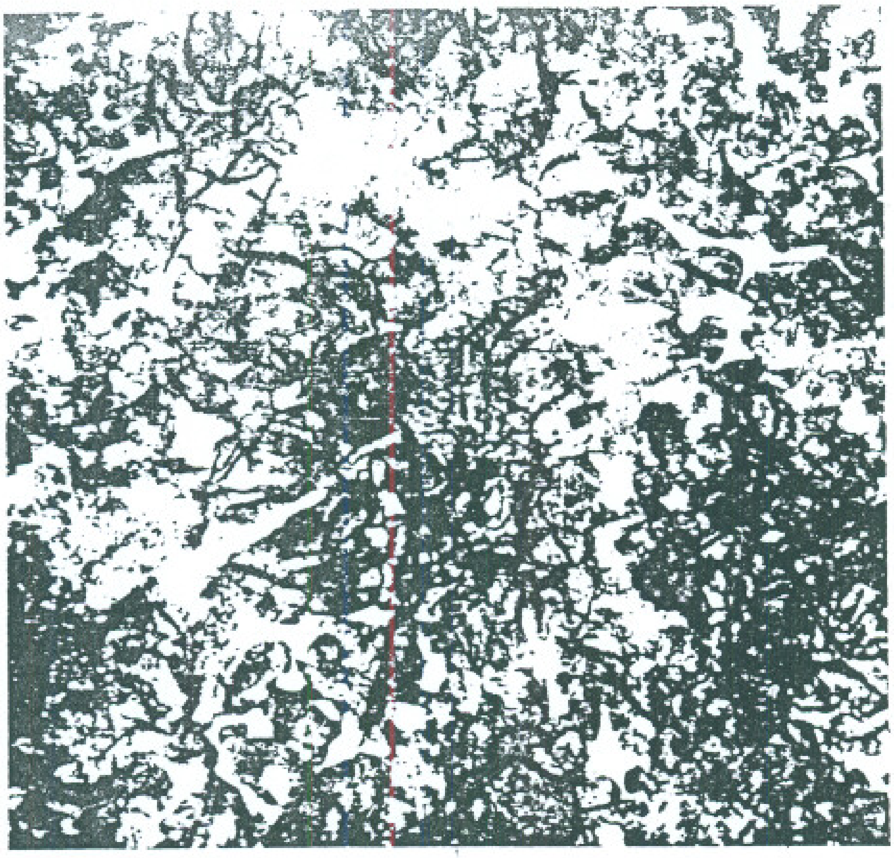


FIG 4

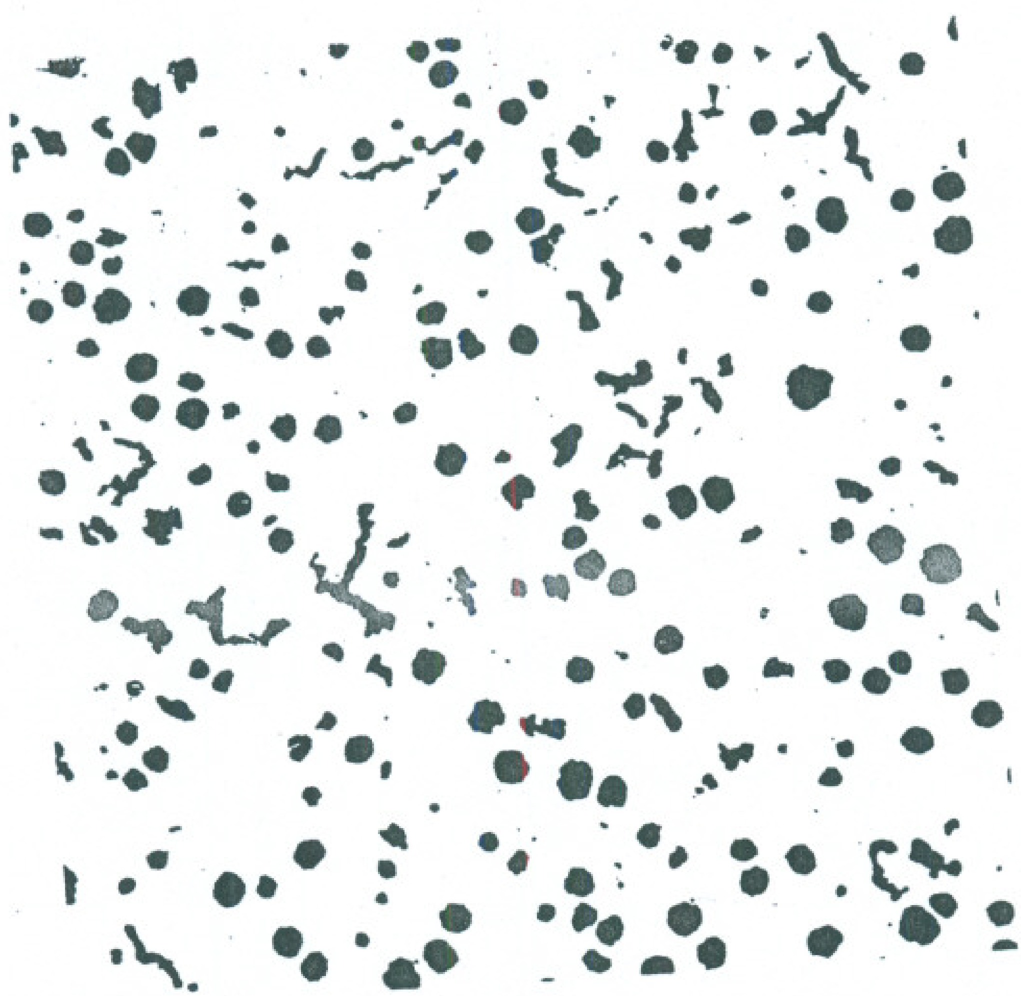


FIG 5

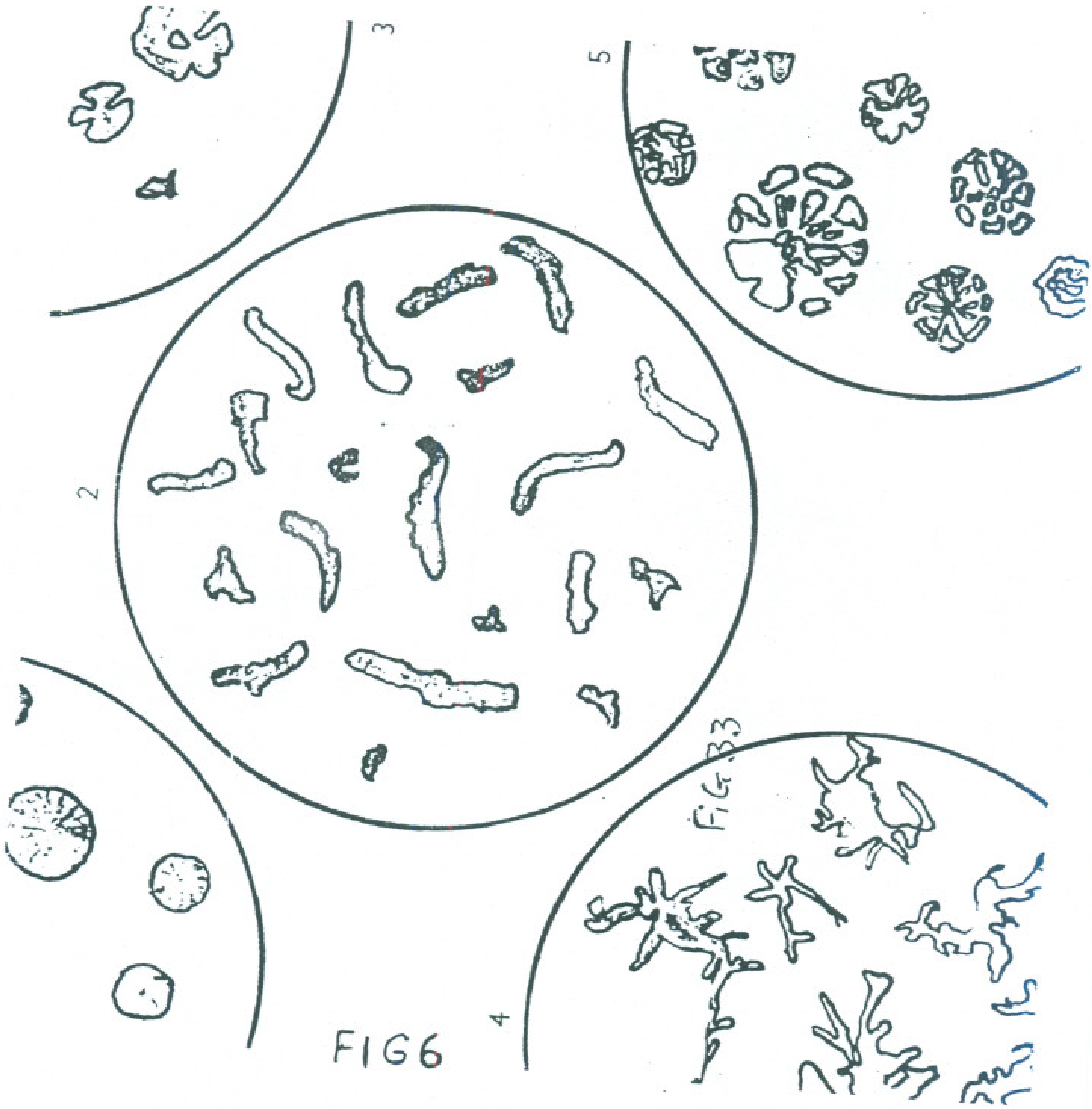

3
5
2
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FIG6