Nodular Iron Gears For Pumping Unit Gear Reducers

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INTRODUCTION

Nodular iron, better known to the industry as ductile iron, is a relatively new material. The development of this material was announced in the United States in 1947. Its ability to satisfactorily perform as a gear material is evidenced in its acceptance by both the American Petroleum Institute and the American Gear Manufacturers Association as a suitable gear material. This acceptance came about only after years of research and field tests by gear manufacturers and, most important, by the users.

The use of this new space age material has certainly not been confined to gears. It has found widespread use in nearly all industries. The production of nodular iron has increased each year varying from 60 to 100% increase over the preceding year. It has been subject to more technical studies and papers than has any other material or metallurgical advancement since its development. It would be impossible to list all the applications of this material for new uses are being found daily as more products are being converted from other materials to nodular iron. The oil industry is using nodular iron for gears, valves, fittings, pump parts, compressor parts and numerous other items.

In spite of its wide use, many people are not familiar with the manufacturing processes, properties and advantages of nodular iron. To properly evaluate it, these facts need to be known.

WHY THE NEED FOR NODULAR IRON?

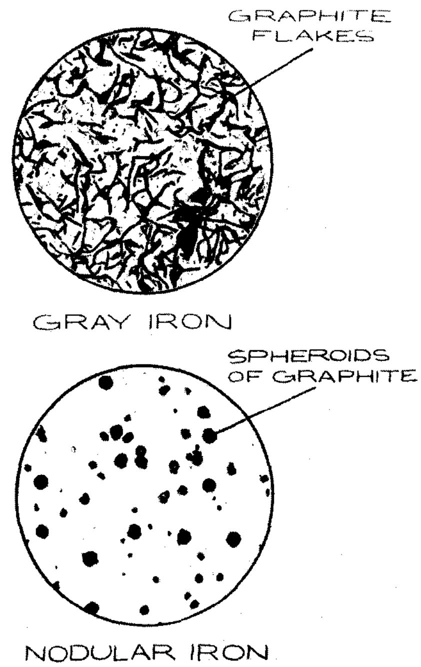
Cast iron and steel have many inherent advantages. Cast iron has good machinability, castability, moderate strength, very good damping properties, good wear resistance, but poor ductibility. Steel has very good strength, toughness, and ductility but lacks machinability and castability. There has long been the need for a material that combines the best properties of steel and iron. Nodular iron fulfills this requirement. It has the machinability, castability, good damping properties, and the good wear resistance of iron combined with high strength, elasticity, toughness, and the ductility of steel.

WHAT IS NODULAR IRON?

The term "nodular iron" is derived from the spheroidal or nodular shope of the free graphite present in the material; this spheroidal shape of the graphite distinguishes the material from gray iron for the free graphite in gray iron is in the form of a flake. The term "ductile iron" is used synonymously with "nodular iron" and, of course, refers to its unusual ductility.

The properties of nodular iron lie between those of gray iron and cast steel, although, in the same hardness range, they compare favorably with steel. The physical properties of nodular iron vary with the chemical analysis and heat treatment; consequently, a wide range of properties is available as in the case of steel.

For understanding more clearly the relationship of nodular iron to gray iron and to steel, the microscope readily becomes a useful tool. A microscopic examination of gray iron and of unalloyed medium-carbon steel reveals the basic structure or matrix of each to be nearly identical; the fundamental difference, of course is the evidence of graphite flakes interspersed with the metal in gray iron but not in the steel. In both materials carbon is present but is in solution with iron in the form of iron carbide lending "toughness" to the material. An excessive amount of carbon is present in gray iron and since it cannot all go into solution with the iron, the excess carbon solidifies -- when the metal cools -- in the form of free graphite and in the shape of a flake. Since graphite has virtually no strength or ductility and since its flake shape provides, in the metal, discontinuities creating internal notches or stress concentration points it reduces the strength and ductility of gray iron as compared with those of steel.



PHOTOMICROGRAPHS
NODULAR AND GRAY IRON
(UNETCHED MAGNIFIED 250 TIMES)
FIG. 1

Looking again through the microscope we would see that gray iron and nodular iron are identical in every respect except that the free graphite in nodular iron is not in the shape of a flake but rather in the form of a spheroid or ball. This is well illustrated in Figure 1 which are photomicrographs of gray iron and nodular iron. While this configuration may appear to be of little or no significance, it has suddenly provided iron with a complete new set of physical properties comparable with steel.

To produce nodular iron having graphite spheroids it is necessary to add magnesium, cerium or other rare earth metals in small quantities to the iron while it is in a molten state. Magnesium changes the metallurgical forces that create graphite, so that when the iron solidifies the graphite assumes a spheroidal shape as compared with the flake shape in gray iron.

The spheroidal shape and dispersion of the graphite in nodular iron presents a high ratio of surface area to graphite volume. This creates a minimum number of points of discontinuities in the metal and results in a stronger, tougher and ductile material. Once the change from flake to spheroidal graphite is made, the physical properties may be further altered by control of the other alloys in the iron and by proper heat treatment.

WEAR RESISTANCE

One of the most important requirements of a gear material is wear resistance. The wear resistance of nodular iron is markedly superior to that of steel of an equal hardness. In the rating of API gear reducers, the hardness used for nodular iron is the same as that used for steel, which means nodular iron gears have better wear risistance than do steel gears in the same gear reducer. This is primarily due to the additional graphite present in nodular iron and the lack of it in steel. The dispersion of the spheroidal graphite is similar to impregnated graphite used in expensive sleeve bearing material. The spheroidal graphite particles serve as reservoirs to store up lubrication for starting up periods and to prevent scoring, galling and scuffing. It also tends to prevent tooth wear during periods of lubrication failure when the lubricant has lost its lubricity. Many tests and case histories have been presented where nodular iron has out-performed steel in its resistance to wear when used as a gear material.

One very good example of the wear resistance and impact strength of nodular iron is illustrated in Figure 2. This is a shake out machine used to shake heavy castings out of the mold. The bed shown, on which the mold is sitting, is vibrated at a high speed which in turn "shakes" the mold and allows the casting to fall free from the mold and the sand to fall free from the casting. This machine was installed in 1956 and was equipped with a steel bed. The original bed lasted less than one year. At that time a type 80-60-03 nodular iron bed was installed. The bed shown in the

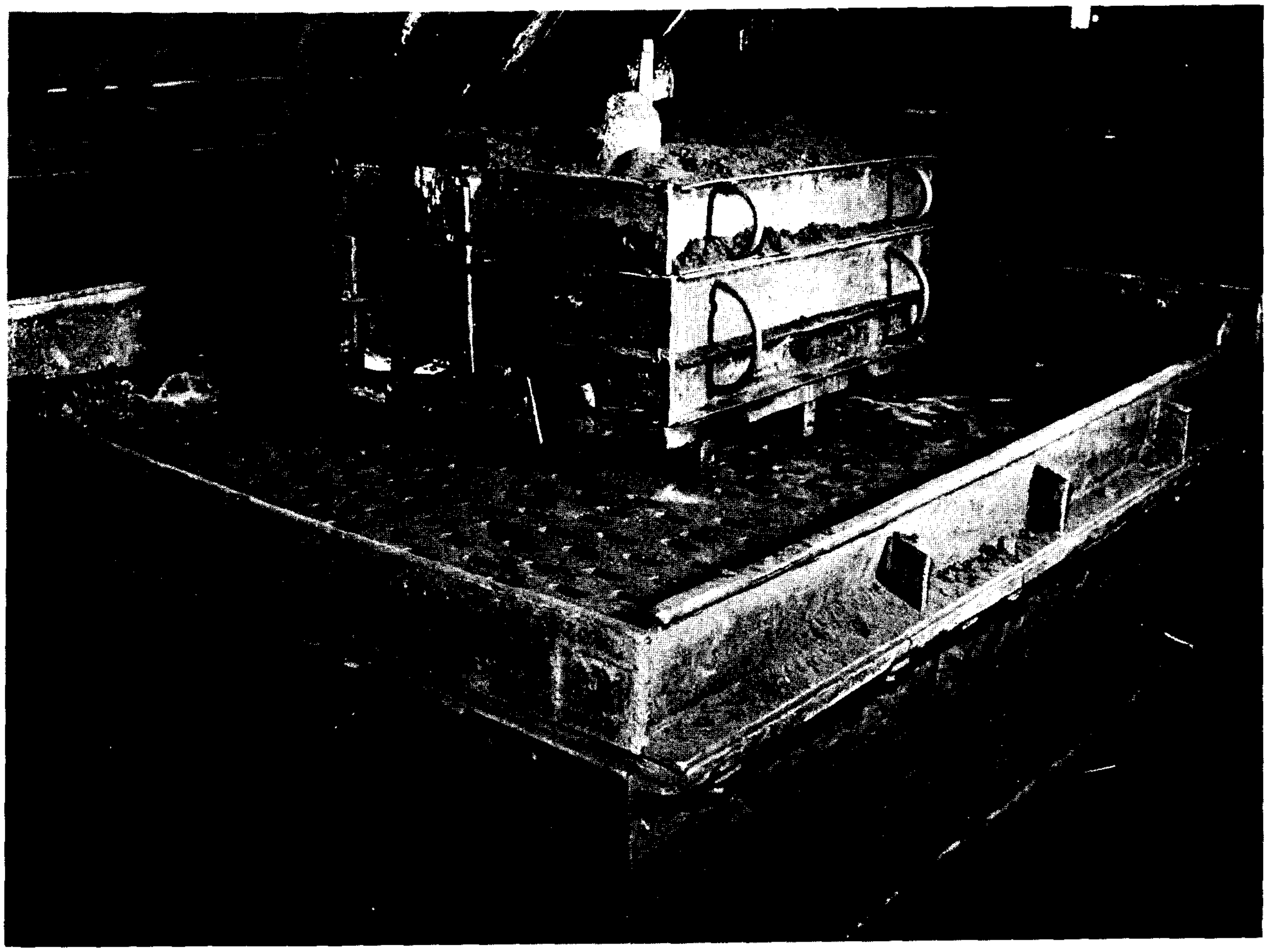


Fig. 2 Shake Out Machine With Nodular Iron Bed.

picture is the one installed early in 1957 and still appears to be as good as new. This machine is used several hours daily handling castings and molds weighing up to 10,000 lb.

DAMPING PROPERTIES

The capacity of gray iron to quell vibrations and ringing, known as damping capacity, is very high. The ability of iron to quell vibrations and dissipate the energy as heat makes it an ideal material for operating machinery. This is borne out in that gray iron has been used for engine bases, slide rails, and other forms of machinery supports. While nodular iron does not have the damping capacity of gray iron, it is approximately twice as good as steel. The relative damping capacities of gray iron, nodular iron and steel are shown in Figure 3. Another way of illustrating the ability of damping of nodular iron is to strike a

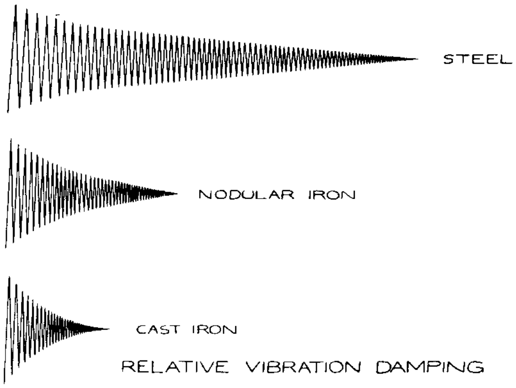


FIG.3 RELATIVE VIBRATION DAMPING

nodular iron casting and a piece of steel with a hammer. The nodular iron will give off a short dead sound indicating the sound vibration being absorbed, while the steel will have a long clear ring.

DUCTILITY

Plastic elongation is used as an index of the ductility of metals. The ability of nodular iron to elongate under strain is illustrated in Figure 4. You will note the test specimen has "necked-down" at the point of fracture. You will also note the length of the specimen has increased from 2 in. to 2.180 in. The ability of nodular iron to elongate and neck-down under load illustrates the ductility of this material.

The samples shown in Figure 5 illustrates its ability to be bent or twisted.

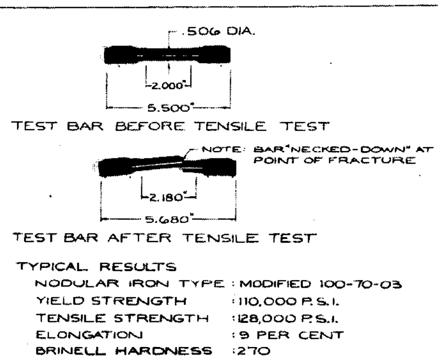
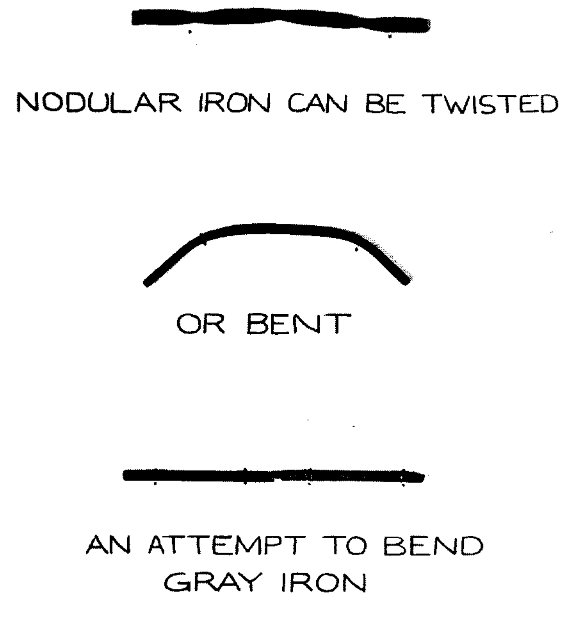


FIG. 4 ELONGATION OF NODULAR IRON



EXAMPLES OF THE DUCTILITY OF NODULAR IRON

FIG. 5

HEAT TREATMENT

The type heat treatment applied to nodular iron depends upon the type and grade desired. Similarly to the steel used for gears, the nodular gear iron is heat treated to obtain the desired hardness and strength. The actual hardness required depends upon the design of the gear train, and normally, a minumum brinell harness of 240, 255 or 270 is used. The A.P.I. hardness requirements of nodular iron and steel are the same for the surface durability rating of gears.

The normal heat treating procedure of nodular gear iron and steel are as follows. First, the gear blank is placed in a furnace with well circulated heat and automatic heat controls. It is heated to 1650° F, which is over the critical point and is held at this temperature for 1 hr per in. of casting thickness. It is then quenched or rapidly cooled in oil using 1 gal of oil per pound of iron and the temperature lowered to 150° F. At this stage the hardness of the blank is in the range of 500 brinell. In order to lower this hardness to a machinable range, the next step is to "draw" the blank. This consists of reheating to 1050 to 1150° F and air cooling. The draw temperature is dependent upon the actual analysis. The close chemical control of nodular iron when poured, means better heat treatment. After drawing, each individual gear blank is checked for hardness to make certain it is within the specified range.

Heat treatment of the steel used in gear blanks is identical except that the temperatures may be slightly different and water may have to be used as a quenching medium to obtain hardness penetration.

Experience has shown that nodular iron responds better than does steel to heat treatment. As the tensile strength of steel and nodular iron is proportional to the hardness, the more hardness penetration the stronger the gear blank. In a heavy section nodular iron gear blank the center of the blank will be nearly as hard as the outer surfaces. In a heavy section steel gear the center will be considerably softer. While the lack of hardness penetration in the steel blank does not affect the surface durability rating of the gear, it does reduce the overall strength.

PHYSICAL PROPERTIES

Nodular iron is manufactured in several different grades, each having certain inherent properties and making it more suitable for each particular application The physical properties for the three most popular grades are tabulated in Figure 6. You will note, the

Type	Tensile Strength P.S.I.	Yield Strength P.S.I.	Elongation Per Cent	Brinell Hardness
60-45-10	60,000 to 80,000	45,000 to 60,000	10 to 30	143 to 207
80-60-03	80,000 to 100,000	60,000 to 75,000	3 to 10	207 to 269
100-70-03	100,000 to 120,000	70,000 to 90,000	3 to 10	241 to 302
C-1045 Steel	105,000 to 120,000	77,000 to 93,000	20 to 24	241 to 277

Fig. 6 - Physical Properties of Various Grades of Nodular Iron and C-1045 Heat Treated Steel.

type designates the minimum physical properties. For example: type 60-45-10 indicates 60,000 psi. minimum tensile strength, 45,000 psi minimum yield strength and 10% elongation. Also tabulated for comparison are the average properties of heat treated C-1045 steel normally used in the manufacture of steel gears.

The type of nodular iron used for gears closely resembles type 100-70-03. However, additional quantities of nickel and manganese are usually added to increase the toughness, for better heat treatment and to insure the elongation being near the high side of the 3 to 10% range. The tensile and yield strengths of nodular iron, as well as steel, increases as the hardness increases. As brinell hardnesses of 240, 255 and 270 are normally used for gears in API reducers, the tensile and yield strengths shown in the table for 100-70-03 nodular iron would apply. You will note how closely the 100-70-03 nodular iron compares with the C-1045 steel in strength.

MANUFACTURING NODULAR IRON

The present day foundry is far advanced from the foundries of just a few years ago. In high production foundries, automation plays a major part. Quality control is an important function inasmuch as irons of all types are now being poured. The steps in pouring nodular iron require even more quality control than the various high grades of gray iron. In Figure 7 is shown the evolution of a nodular iron gear, which illustrates the steps in manufacturing a nodular iron gear.

The charge for the cupola is made up of 34% steel, 40% pig iron and 26% returned nodular iron scrap. Each piece of metal used is carefully selected and weighed so that the correct chemical properties are insured.

The charge is then heated in an acid lined cupola. Other types of cupolas may be used but the acid lined is the most popular.

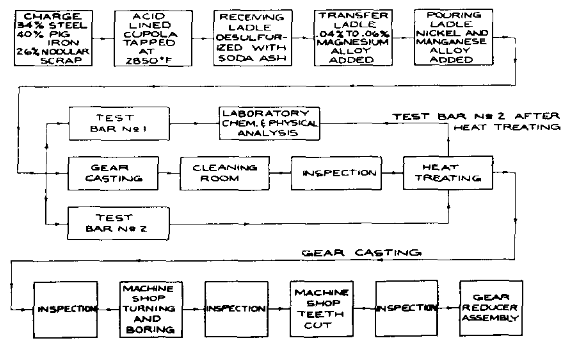


FIG. 7 EVOLUTION OF A NODULAR IRON GEAR

The cupola is tapped when the molten iron has reached a temperature of 2850° F. The pouring temperature is very closely supervised and controlled.

The iron is first poured into a receiving ladle containing granular soda ash. This is to reduce the sulfur content. The presence of sulfur serves to reduce the effect of magnesium and if it is not held to a very low level, considerably more magnesium must be added to produce spheroidal graphite.

The iron is then poured into a transfer ladle containing .04 to .06% magnesium alloy. It is here that the transformation to nodular iron takes place. The metallurgical forces that create graphite are changed here by the magnesium so that when the iron solidifies in the mold the graphite assumes a spheroidal shape instead of a flake shape.

In the next step the iron is transferred to the pouring ladle. At this point nickel, manganese, and silicon are added for extra toughness, better heat treating and more elongation.

From the pouring ladle the iron goes to three points: the casting mold, in which the imprint of the gear pattern has been made in hard packed molding sand, and into two molds for test bars. These test bars serve two purposes. One test bar is immediately delivered to the laboratory where it is checked for chemical and physical properties to make certain the transformation to nodular iron is complete. Should something be amiss in these properties, all castings poured from this heat are scrapped immediately. Each casting carries a heat number which corresponds to the heat number on the test bars so the casting may always be identified and the chemical and physical properties known. The other test bar is sent with the castings for heat treatment and receives the same heat treatment as the gear castings. It is then returned to the laboratory for chemical and physical analysis. As the first test bar insures good nodular iron and the second test bar insures proper heat treatment, we are certain of a well made gear blank.

The gear casting is removed from the mold; and gates, risers, etc. are removed in the cleaning room. At this point the gear blank receives its first inspection. It is thoroughly inspected for any casting defects and checked for size.

Heat treatment is the next step. From the test bar the heat treater is given the actual chemical analysis taken from which he determines the proper heat treatment.

After heat treating, the gear blank is inspected again. This inspection includes a hardness check to make certain the proper hardness has been obtained.

While economics prevent all gear blanks from being X-rayed, a representative number are X-rayed to check for internal defects. Should any gear blank of a particular size show internal defects, all gear blanks of that size are X-rayed before being used. Changes in the mold design are immediately made to eliminate possible internal defects.

The gear blank is then sent to the machine shop for turning and boring, after which it is returned to inspection and all machining is checked. It is then returned to the machine shop and the teeth cut. The finished gear is again inspected for tooth finish, tooth size, etc After this inspection it is then ready for assembly in a gear reducer.

All these steps illustrate the amount of work and knowledge required to manufacture a good gear. A good gear just does not happen by accident. It is a combination of metallurgical knowledge, foundry experience, proper machining and close inspection at every step

SUMMARY

The use of nodular iron as a material for gears in pumping unit gear reducers is certainly not a "cure-all" for all the gear problems encountered. However, experience in thousands of gear reducers has indicated that the inherent properties of nodular iron are such that many problems encountered are eliminated or minimized. Some of these advantages are listed below:

(a) The better wear resistance of nodular iron tends to increase the life of the gears not only of those subject to loading within their capacity but also in cases of overloading. The well spread spheroidal graphite serves to provide lubrication and thus help to reduce pitting, galling, scoring, burning, scuffing and abrasive wear.

This property is illustrated in Figures 8, 9 and 10 The gear train shown in Figure 8 is an API size 228. This gear reducer has been in operation nearly two years and is operating just below its rated capacity. The slow speed and high speed gears are nodular iron. You will note the absence of any type of visible wear on the gear teeth. In fact there has been so little wear in this gear reducer that the gear generator cutter marks are still apparent on the steel slow speed pinion.

The gear trains shown in Figures 9 and 10 are API size 114. These were installed March 1960. Both have been subjected to considerable overload and fast pumping The slow speed and high speed gears in Figure 9 are steel. Evident on the teeth of both gears is continuous pitting because of the overload under which they have been operating. The slow speed gear in Figure 10 is steel while the high speed gear is nodular iron. The steel slow speed gear shows continuous pitting similar to the steel gears in Figure 9, but in the high speed gear, while to some extent pitted because of overload, the pitting is not continuous or as extensive as is the pitting on the steel high speed gear shown in Figure 9.

(b) Through the reduction of the amount of vibration being transferred the damping property tends to lower the noise level of the reducer. You will find that a gear reducer equipped with nodular iron gears usually runs considerably more quietly than do those with steel gears.

(c) The ductility of nodular iron, while not as

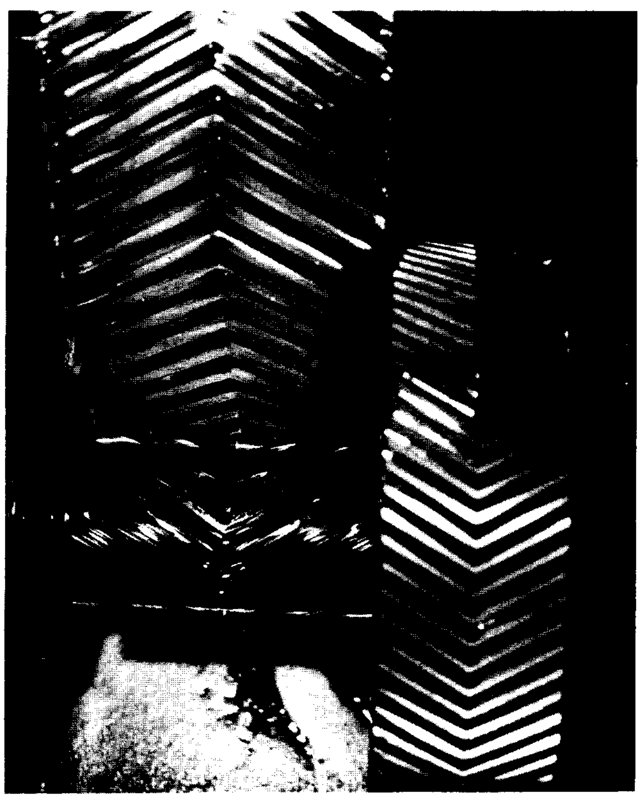


Fig. 8 A.P.I. Size 228 Gear Reducer With Nodular Iron Gears

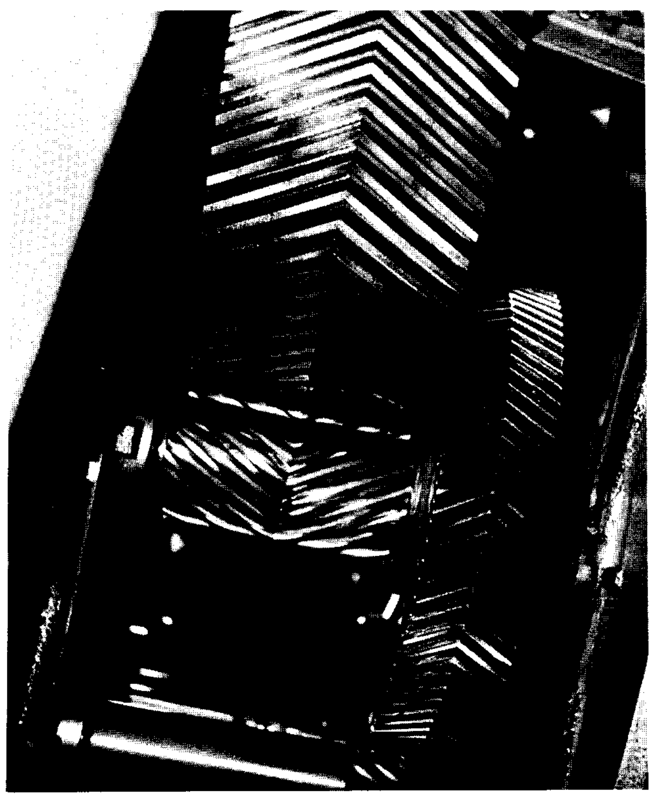


Fig. 9 A.P.I. Size 114 Gear Reducer With Steel Gears

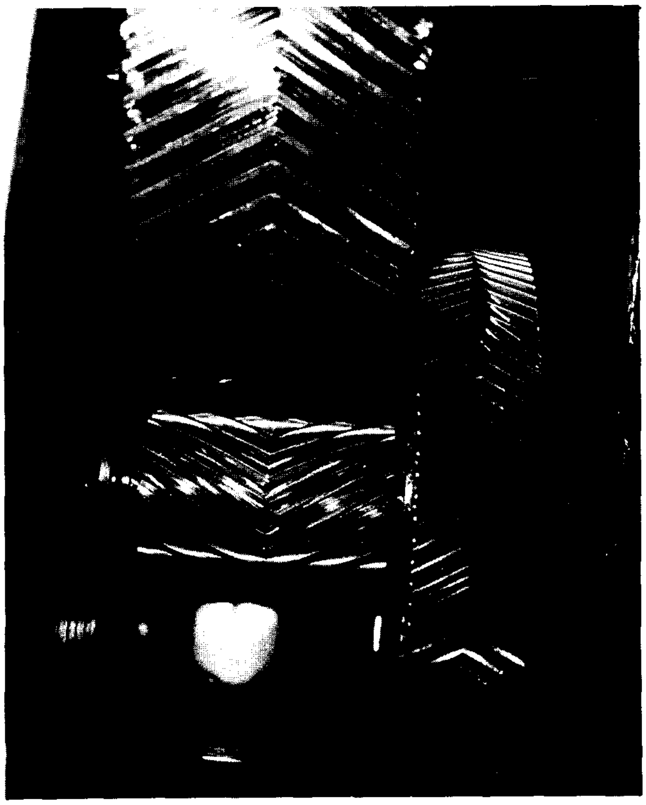


Fig. 10 A.P.I. Size 114 Gear Reducer With Nodular Iron High Speed Gear and Steel Slow Speed Gear.

great as that of steel, is far more than sufficient to withstand the impact loading from gas or fluid pounds and rough running engines.

(d) Another factor in favor of nodular iron is its low modulus of elasticity, which is 80% of that of steel. This gives it the ability for the teeth to bend more under load without harmful effects, and, as a result, there is better distribution of the load.

(e) The better castability of nodular iron as compared to that of steel means sounder castings free of internal defects.

(f) Nodular iron has better machinability for more accurately cut gear teeth. A better surface finish results in a more even distribution of load on the gear teeth.

(g) The chemical properties of nodular iron lend themselves to better heat treatment. The superior hardness penetration results in a stronger gear blank. Also, a more even hardness is obtained which eliminates hard spots which means more accurate machining of gear teeth.

(h) The tensile and yield strengths are comparable with steel and result in good fatigue properties.