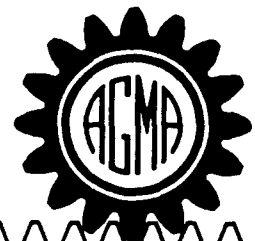


Ductile Iron as a Gear Material

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American Gear Manufacturers Association



TECHNICAL PAPER

Ductile Iron as a Gear Material

Peter Graham, Graham Campbell Ferrum Co., Pty. Ltd.

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

The paper covers an outline of what Ductile iron is, and the typical type of metallurgical structures which could be expected for gearing; the physical properties which can be expected from the different grades of Ductile iron; the types of heat treatment and the effects on the properties which can be expected; and also hardness figures can also be provided in the gear blanks. The paper also looks at clarifying the allowable contact stresses for the Ductile iron in the As Cast grades and the Normalized grades. It also outlines some of the machinability aspects, surface finish and the AGMA levels which can be achieved for the large gearing.

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1500 King Street, Suite 201
Alexandria, Virginia, 22314

October, 1999

ISBN: 1-55589-745-2

DUCTILE IRON AS A GEAR MATERIAL

Steel has been traditionally used for the supply of the larger gear castings. This has primarily been because the Cast Iron was not strong enough in tensile strength. A new material was developed in the 1940's and this new material was called Ductile Iron. It was a material that was to become a marriage of properties between that of Cast steel and Cast Iron. The Ductile Iron has the strengths of the cast steel and the castability and machinability of Cast Iron.

The Ductile Iron is a material that has grown tremendously in its uses and applications, typically replacing Cast steel, Forged steel and Cast iron. In relation to the gear market, the Ductile Iron is offering a real alternative to the Cast Steel and Fabricated Steel gear designs. It offers a series of advantages to the suppliers of grinding mills:

- a) Delivery.
- b) Price.
- c) Performance.

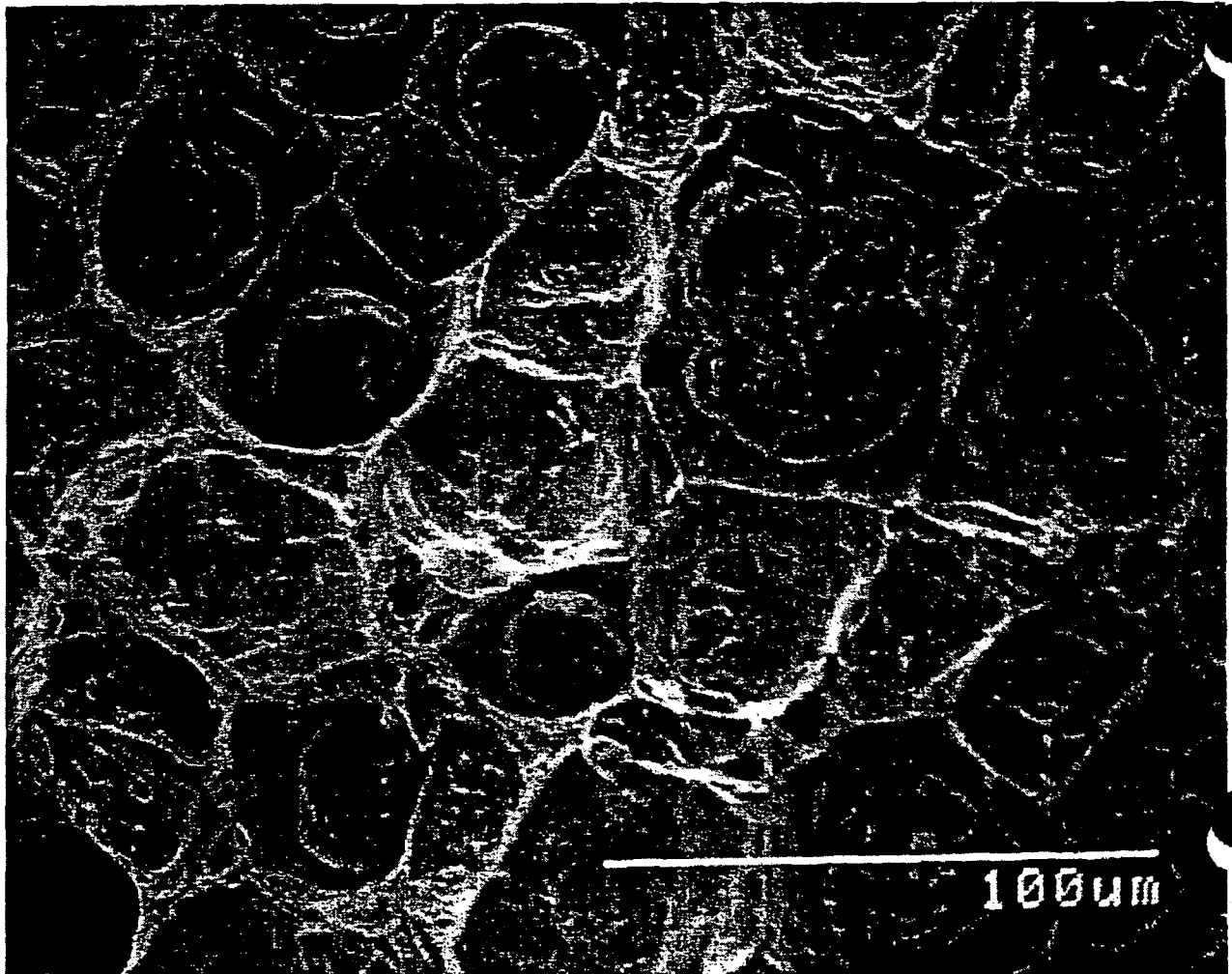
Our company has been manufacturing Ductile Iron gears since 1976. In that time the size of the gears has increased and also the horse power which is being put through them has also increased. Since the first mill gear was installed in 1980, GCF has never had a gear wear out or fail in service. The number of gears which our company has put into service is in excess of 200, with the gears working in the cold of Alaska, the heights of the Andes in Chile and the heat of Africa. The largest gear which we have made was 37' diameter with a face width of 40" and transmitting 7000 Hp.

What is Ductile Iron:

Ductile iron is a cast iron which has had the flake graphite form changed to a graphite which is now in a nodular form through the addition of magnesium. Ductile Iron has a Steel matrix which have a lot of graphite balls dispersed throughout the matrix. Ductile Iron is also known as Nodular Iron, and SG Iron (spheroidal graphite). The size of the graphite balls range from 10 to 50 microns in diameter, and the nodules of carbon are typically spherical and they sit inside a shell or cavity of metal. It appears that the graphite ball has clearance between itself and the metal matrix. This is I believe a very important aspect of the Ductile Iron and assists in answering why the material works so well in operation.

The Ductile Iron matrix can have combinations of :

- a) Ferrite
- b) Pearlite
- c) Bainite
- d) Martensite
- e) Ausferrite (ADI)



Graphite Nodules in the Ductile Iron Matrix

These above matrix combinations are all found in steel and are typically no different. The real difference between steel and Ductile Iron is that there is a massive amount of carbon, which is tied up in the form of free graphite in the nodules of the Ductile Iron. It is therefore a relatively simple process to provide a variety of hardness ranges for the gears made in Ductile Iron, by achieving it through the use of alloys, heat treatment, or both.

Ductile Iron for gears should have a microstructure that is formed of predominantly nodular graphite, with a pearlitic matrix. It may have varying degrees of Ferrite or Bainite or potentially Austenite depending on the gear size and the hardness's required. The structure should not show flake, laminar, chunk or exploded graphite. Grain boundary carbides and non-metallic inclusions need to be minimised, through good metallurgical control.

Gear casting/pouring methods.

This paper is covering the basic properties and advantages that Ductile iron offers, however it is also important to understand a little of the manufacturing methods that are required to make this material.

Cast steel solidifies directionally. This basically means that larger sections feed smaller sections and therefore the full ring riser method is a more traditional method, which is used to help provide a clean, solid gear face. This also means a lot of extra metal needs to be poured to guarantee a solid casting. This is also a reason why the "Y" section gears are preferred for the cast steel gears. It is a lot easier to feed a "Y" section gear than a "T" section gear cast in steel. This makes the steel casting yield range from 50 -60%.

Ductile iron is totally different in its method of solidification and as such this also changes its methods of manufacture when completed to steel. Ductile iron does not solidify directionally. Heavy section Ductile iron castings are always cast without feeding risers. There are a series of important principles which need to be considered, however one of the most critical is to make all the cross sectional areas think that they are the same section thickness. If this occurs then the gear will solidify at the same time and the graphite expansion that occurs on solidification can then complete the feeding of the casting. To make the casting cool at the same time it is necessary to "chill" the gear rim, so that it thinks that it is the same section thickness as the web section, which bolts on to the shell. It is there for possible to cast Ductile iron gears with an 85 - 90% yield.

The difference between having to put the risers on for steel castings and that no risers are required for Ductile iron castings, allows for the Ductile Iron casting to be made more quickly, poured with less metal and stripped from the mould, within 24 hours of pouring. Gear castings which are made in Ductile iron can be delivered within a week after pouring to the machine shop.

Gear Material Hardness's

There are some very interesting considerations that need to be analysed when comparing the hardness of **Steel to that of Ductile Iron**. If we were to consider that a Steel and a Ductile Iron were to have the **same hardness of say, 300 BHN**, are they in fact having the same hardness. In reality it would seem so, however it is not true.

Both materials may have the same pearlitic structure, however when we consider how the microstructural matrix of Ductile Iron is made we find that the Graphite Nodules are sitting in a cavity which has clearance between the graphite sphere and the metal matrix.

When a Brinell load is applied to a Ductile iron sample, the graphite cavities collapse in on themselves as the load is applied, yet the hardness ends up as the same as that of the steel which has no graphite cavities. This implies that the base matrix hardness is in fact a lot higher than that of a comparable hardness steel, and that the matrix also has a higher compressive resistance.

The macro hardness is relative to the structure. If it is a ferritic structure it will be softer than a corresponding pearlitic structure. If using alloys generates a typically fully pearlitic structure for an as cast gear, the Brinell hardness may range from 245 BHN to 285 BHN. This also implies a range for the micro hardnesses. The micro hardness will also be higher than the base Brinell hardness. If a **micro hardness** test is done on the Ductile Iron matrix of a pearlitic gear, with the gear showing a Brinell hardness of 275 BHN, the corresponding **micro matrix hardness** range will be from **300 to 360 BHN**.

When the same “as cast” gear is given a Normalising and Tempering heat treatment and the structure is stabilized at a consistent temperature (1650 F) from which the gear is then air cooled. This air cooling then gives a consistent cooling rate, which will be quicker and more uniform than what happens within the mould. The typical hardness range, which our company achieves on the gears that have been Normalised and Tempered, is between **295 to 320 BHN**. The hardness range is a lot more consistent than the as cast gears. The fineness of the structure is more consistent, and the micro hardness range is also a lot narrower in its range and it is higher. The spread of the **micro matrix hardness** range is smaller at **350 to 380 BHN**.

These variations in results are also revealed when an **equitip** is used. The hardness results of the equitip on Ductile Iron gears tend to have a wider range. The high results come from the higher hardness matrix areas being tested as opposed to the lower results from an area which may have a higher number of graphite nodules or areas of ferrite. The equitip indenter is also too small for credible results to be achieved with Ductile Iron. As such it is not considered an acceptable method for testing large Ductile iron gears.

Ductile Iron is able to offer a wide variety of hardness, from 180 - 350 BHN. Higher hardness's in the range of 320 - 450 BHN can be achieved, however a much higher alloy addition is required. The structure is typically **Bainitic**, and is extremely tough to machine, drill and tap and gear cut. It is also more expensive to make as it tends to be more susceptible to potential shrinkage defects and the amount of alloys required. This material can be Normalised and Tempered in the same manner as the lower alloyed grades, however the hardness increases enormously into the range of **400 - 550 BHN**. The structure is tempered Bainite, Martensite and can have some retained Austenite. It may also contain some carbides of Molybdenum, Manganese or Chrome. This material will work harden up to 650 BHN.

Due to the higher Carbon contents in the Ductile Irons, it is easier to achieve higher hardness in the Ductile Iron gears than in the steel gears. Ductile Iron also has the ability to provide better through section hardnesses in the gear rim. It does not suffer the drop off in hardness values to the degree that cast steel does as the section thickness increases.

The use of full ring risers that are required to feed liquid metal to the steel gears, creates a thermal centre which is generally situated at the cope or top face of the gear. This “centre” of the casting can suffer from excessive grain growth and cell boundary inclusions due to the very slow cooling. Ductile Iron on the other hand does not need to have any risers on the gear and as such