LOW-GRAVITY SOLIDIFICATION OF CAST IRON AND SPACE TECHNOLOGY APPLICATIONS

by

James A. Graham
Deere and Company
Moline, Illinois 61265

DISCUSSION

Deere has performed a limited number of tests on the solidification of cast irons in the low-gravity environment provided by the KC-135's and the F-104 aircraft. The results today are very promising, although we have not satisfied our total curiosity about the influence of low-gravity on the graphite formation and microstructure of cast irons.

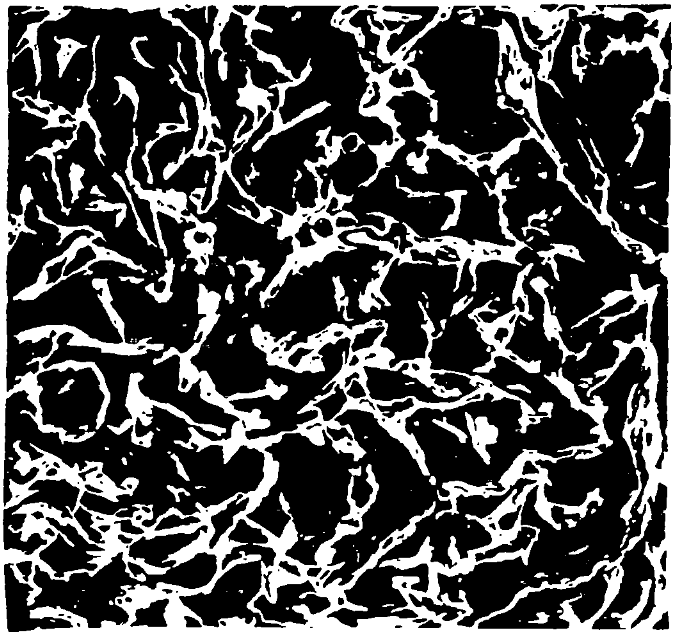
Deere is the world's largest manufacturer of farm equipment. A few of our products are: tractors, combines, tillage, planting and harvesting equipment. We also manufacture a line of industrial equipment, including earthmoving and forestry products. Included in our product line are mowers, tractors, and other lawn care equipment.

Cast irons make up about 25% by weight of our products. We have some of the largest foundries in the country outside of those operated by the automotive companies. We produce 3 grades of iron: gray iron, compact graphite and ductile iron. The table below shows the properties of these irons.

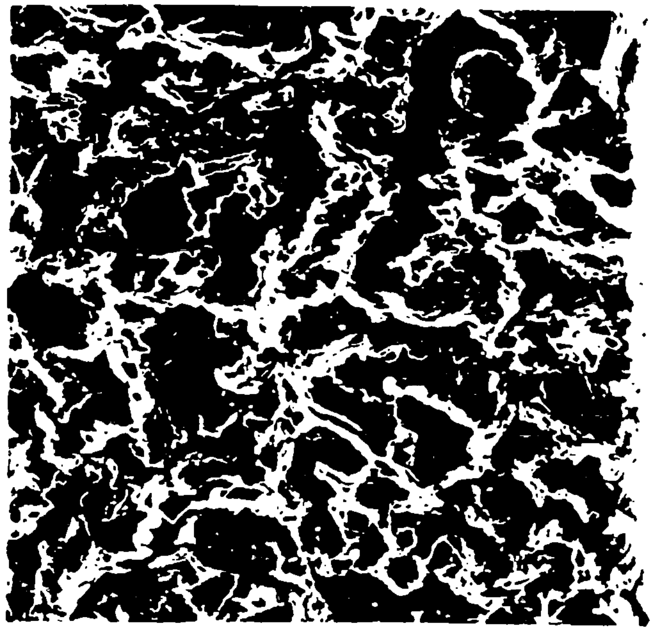
TABLE 1. DEERE CAST IRON PROPERTIES

Iron Type	Min Tensile Strength MPa	Mean Hardness MPa	Elastic Modulus GPa	Thermal Conductivity W/M°C
Gray	200	2100	100	48
Compact	300	2100	135	43
Ductile	550	2100	175	29

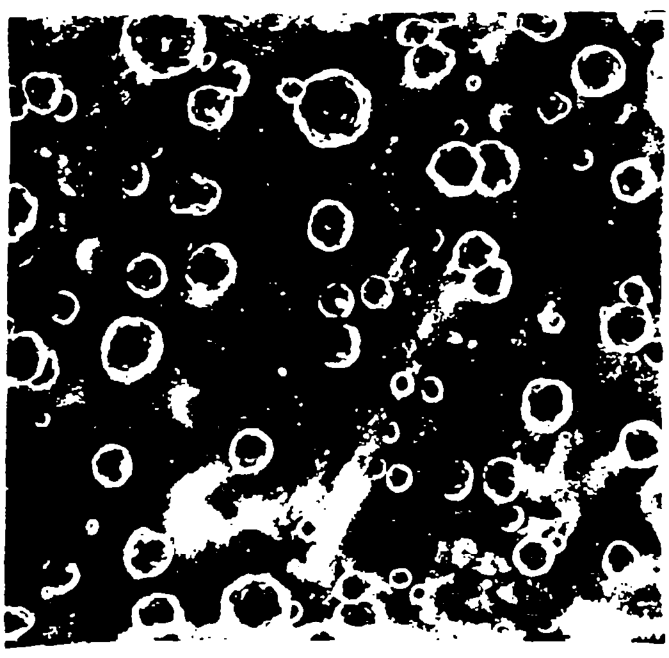
Typical microstructures of these cast irons are shown in Figure 1.



GRAY IRON



COMPACT GRAPHITE IRON



DUCTILE IRON

Figure 1. Typical microstructures of cast irons (deep etched, 200X).

Gray iron has interconnected flakes of graphite much like corn flakes in a box. Around the graphite is a matrix of metal.

Ductile iron has spheroidal graphite formations whereas compact graphite is similar to flake, but with rounded edges lowering the stress concentrations due to notches that you find in the gray iron. The gray iron, by its nature of the many notches all around the graphite flakes, is quite brittle. It exhibits little or no ductility whereas the compact graphite iron has a higher strength and exhibits some ductility and the nodular iron with the spheroidal shapes of graphite exhibits significant ductility and higher tensile strength.

Our involvement with NASA started about four years ago through the American Institute of Aeronautics and Astronautics program of visits for industrial firms to the NASA research centers. On these visits to each of the NASA research centers, we observed many things of interest to us. We also had visits by Harry Atkins and others of the Marshall Space Flight Center team on materials processing in space and by Nancy Williamson and other personnel from Rockwell International who were promoting the utilization of the shuttle. These visits revealed some of the possibilities for processing materials in space.

Shortly before these visits, we were requested by a museum to slice some meteorites. These meteorites exhibited graphite formations in basically stainless steel, very similar to the graphite formations in ductile iron. If these nodules occurred naturally in space as the meteorite cooled, what would be the influence of gravity on the graphite formations in our cast irons? This question began the discussions of conducting tests in the low-gravity environment on each type of Deere cast iron.

This was suggested to the people at Marshall Space Flight Center and we began our discussions on conducting appropriate experiments. The scientists at Marshall had developed a furnace which was deemed appropriate for melting and solidifying small cast iron samples in the KC-135 aircraft. The sample, itself, was 8 mm in diameter by 20 mm in length. It was placed in the crucible and into the insulated furnace.

At Deere we performed two types of analysis: (1) A theoretical analysis using the computer to predict the cooling versus time throughout the small test specimen. To verify the calculations and the test equipment, we conducted, in our research foundry laboratory, tests to generate a cooling time curve for the cast iron in the furnace. A typical graph is shown in Figure 2.

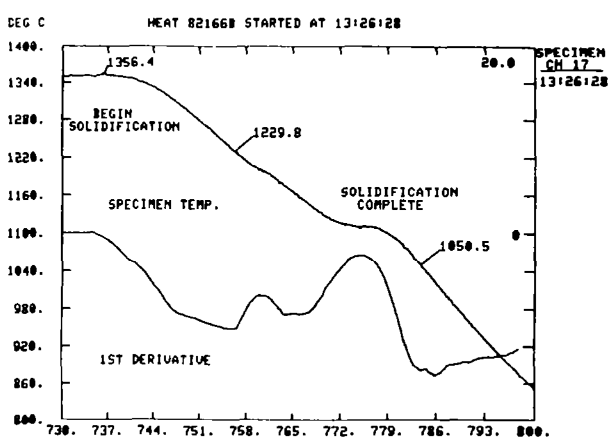


Figure 2. Cooling curve for low-gravity sample conducted in ground-based laboratory.

The objective of the test was to be able to cool the cast iron through the solidification period while the aircraft was going through a period of low-gravity. The period of low-gravity was just barely sufficient in the F-104 aircraft to solidify the iron at low-gravity. However, prior to the low-gravity period, we had a period in which the gravity was substantially over 1-g.

The initial flights were conducted on a KC-135 in which we had a period of about 30 seconds of low-gravity. We then switched our operations to the F-104 where we had a period of approximately 55 seconds of low-gravity. With the difficulty in being able to solidify the iron at exactly the right time in relationship to the low-gravity, we did see some influences on the microstructure. The results today indicate that the primary mode of graphite transport is by diffusion.

When the results of our tests, those by Bethlehem Steel in the same test program as ours and the work done by Dr. D. Stefanescu at the University of Alabama in Tuscaloosa with a directional solidification furnace, there appears to be considerable promise in continued experimentation in the solidification of cast iron at low-gravity.

We are, of course, concerned about the producibility and the cost of producing cast irons. For the sake of performance and durability, we must keep the strength level up. If we increase the hardness to obtain the strength, the tool-life during machining is low and if we try to obtain the increased strength at low hardness we then have poor castability in the foundry.

Anything that we can do to open this window would be very useful in production. Also, increasing the ability to control the process and stay within the allowable window would make the production of quality irons easier.

In studying the results obtained to date, it appears that we have three areas in which we can obtain additional information by further tests at low-gravity. These are:

FUTURE SUBJECTS FOR LOW-GRAVITY TESTS

PROCESS MANAGEMENT

- CARBON FLOTATION
- HIGH CARBON IRON PHASE DIAGRAM
- CELL SIZE CONTROL
- DIFFUSION MEASUREMENT LIQUID-SOLID
- QUANTIFY DIFFERENCE CAUSED BY LACK OF CONVECTION

DESIGN DATA

- TRUE LIQUID THERMAL CONDUCTIVITY
- PROPERTIES OF HIGH CARBON

NEW MATERIALS

These possibilities are currently under study and will require ground base tests for comparison purposes and tests to verify the functioning of low-gravity equipment. Low-gravity tests are envisioned for the F-104 and KC-135 aircraft, and also there is the possibility that the space transportation system will be required to obtain longer time periods for the low-gravity tests.

The interaction between Deere and NASA has extended over several other different subjects. For instance, our machines contain various functional elements as shown below.

FUNCTIONAL ELEMENTS

ENGINES	MONITORS
TRANSMISSIONS	AIR CONDITIONING
HYDRAULICS	CUTTING
COOLING SYSTEMS	SEPARATION
CONTROLS	CLEANING
ELECTRONIC	STORAGE
MECHANICAL	
HYDRAULIC	

Many of these functional elements also are present in the equipment designed and used by NASA. Our machines are made up of various materials such as:

MATERIALS

CARBON STEELS	ALUMINUM
ALLOY STEELS	COPPER
CAST STEELS	PLASTICS
CAST IRONS	COMPOSITES
POWDERED METAL	RUBBER
PLATING	PAINTS
HARD FACING	LUBRICANTS

Some of the materials are also used in NASA equipment.

In the Deere visits to NASA research centers, we observed many subjects of common interest. One was materials technology. Several areas under materials technology were observed at NASA and many of these were discussed in detail between Deere and NASA personnel as shown on the following page.

Materials Technology

	Observed at NASA	Deere/NASA Discussions
Composites	X	X
Ceramics	X	X
Advanced Materials in Design	X	X
Organic Coatings	X	
Non-Destructive Testing	X	X
Physical Metallurgy	X	X
Fracture Analysis	X	X
Adhesives	X	X

Many types of manufacturing processes are used in producing our products. The table below shows which processes were observed at NASA and also the detailed discussions between Deere and NASA personnel.

Materials Processing

Foundry Technology		
Metal Processing	X	X
C.G. Iron		X
H.I.P.	X	X
Ductile Iron		X
Heat Treating		
High Energy Processes	X	X
Gray Iron		X
Welding	X	X

The pressure is on for increasing the utilization of technology. This is needed for the future competitiveness of the companies in this country and to maintain a reasonable level of exports to other countries.

The competition among the companies and countries producing high technology equipment is becoming more intense and we need to continue to upgrade our level of technology to maintain our competitive edge. The Third World, by necessity, is having to produce some products that formally were produced in this country and in some of the other developed countries. The Third World is also struggling to produce their own food with substantial opportunity to increase the production of food in a number of countries.

The number of engineering graduates in this country is substantially less relative to the total population than in Japan, thus providing them with increased technological capabilities to compete with us even stronger. In the future we will need a higher quality of engineers. We must make up for the lack of numbers in the quality and depth of the engineers. We feel the use of technology, developed for the space program, should be applied to products that can improve the business climate in this country and our competitiveness with other nations.

There have been substantial benefits to Deere. These include the intellectual insights from scientists within NASA who have unique objectives substantially different than the objectives of our own in-house scientists. It also provides the means to accelerate the introduction of advanced technology.

NASA has also benefitted from this relationship through the increased interaction with scientists in another industry and the realization that the NASA technology can be applied to non-aerospace products and processes. However, there are a number of steps that can be taken both by NASA and by industry to help in the future. NASA can improve the environment for the utilization of technology. NASA, by charter, must cooperate with other nations; however, first priorities should be the needs of the industry in this country. Other nations should not be helped to gain a competitive advantage over U.S. industry.

NASA can contribute substantially to the U.S. industrial superiority through the application of the technology they develop. We, in industry, can also take some steps to help ourselves and the country. One of these is to take positive steps to find the technology NASA has available and apply it to products today. Let's jointly tell NASA what we need so they can be considered in future plans. This will aid us in obtaining more results from our tax dollars that go to the very important mission of the NASA organization.