ADVANCEMENT OF IMPERVIOUS GRAPHITE/SILICON CARBIDE MATERIAL
FOR USE IN
SEVERE CORROSIVE AND ABRASIVE APPLICATIONS

BY: J. M. Smerek and T. P. Graves
Union Carbide Corporation
Carbon Products Division
Cleveland, Ohio 44101

INTRODUCTION

A problem common to many industries exists in the handling of corrosive-abrasive fluids. A solution to this problem is the specification of a long-wearing, corrosion-abrasion-resistant material. This paper will discuss a method for solving this problem and offer data to support this solution.

For several decades, impervious graphite has been used successfully in severe chemical processing applications. Types of equipment which employ impervious graphite material include heat exchangers, ground anodes for impressed current cathodic protection, and horizontal centrifugal pumps. For the purpose of this paper, we will limit our discussion to applications involving centrifugal pumps. A selection of the more common corrosive chemicals in acidic and salt solution, where impervious graphite pumps can be or have been used, is illustrated in Table 1.

TABLE 1

SAMPLING OF CORROSION RESISTANCE OF IMPERVIOUS GRAPHITE

CHEMICAL	CONCENTRATION WEIGHT, %	TEMPERATURE °C (°F)
ACIDS		
HYDROCHLORIC	ALL	BOILING
PHOSPHORIC	0-85	BOILING
SULPHURIC	0-70	BOILING
SULPHURIC	70-85	170 (338)
SULPHURIC	85-90	149 (300)
SULPHURIC	90-93	71 (160)
SULPHURIC	93-96	ROOM
SALT SOLUTIONS		
ALUMINUM CHLORIDE	ALL	BOILING
COOPER SULPHATE	ALL	BOILING
FERRIC CHLORIDE	ALL	BOILING
FERROUS CHLORIDE	ALL	BOILING
ZINC CHLORIDE	ALL	BOILING
ZINC SULPHATE	ALL	BOILING

PROBLEM:

Experience has shown that a significant percentage of solids run through a centrifugal pump will cause particulate erosion in the volute case, which contains the fluid, and the impeller, which moves the fluid. The rate of erosion of a part is dependent upon the particulate velocity relative to that part. Although impervious graphite pumps are susceptible to particulate erosion, the problem caused by pumping particulates is not unique to graphite.

An example of particulate erosion of an impervious graphite impeller which was used in a ferrous chloride solution contaminated with approximately 20% solids is shown in Figure 1. This pump was in service approximately two months. Note the scoring of the vanes and the severe erosion around the pressure relief holes. Examination of the eye area at the center of the impeller indicates that the problem was not related to cavitation, which is a result of insufficient Net Positive Suction Head in the system. This example of marginal serviceability is typical of applications where a long recognized need for an erosion resistant form of graphite has been present.

METHOD OF SOLUTION:

One method of eliminating this erosion problem was studied in a 1964 development project. A thin layer of silicon carbide was applied to some graphite pump parts which were subsequently resin impregnated to achieve imperviousness. Pump parts were subjected to severely abrasive slurries at high particulate velocities. The study demonstrated that the success of any hard facing of impervious graphite pump parts to combat erosive attack requires a dense, continuous, and tightly adhering coating. Although laboratory results of this test were encouraging, the costs were prohibitive.

A second method for increasing the erosion resistance of impervious graphite was recently investigated. This technique involves the placing of the machined part in a high temperature furnace containing silicon monoxide vapor. The vapor diffuses into the pores of the graphite, reacting with the carbon.[1] This chemical vapor reaction (CVR) process is used commercially where the dimensions of the finished parts must be maintained, an important advantage because of restrictions imposed by centrifugal pump designs, such as close tolerances and even mass distribution (which affects dynamic balancing of rotating parts, such as the impeller). An additional benefit of this process, which results from the gradual interface between the graphite substrate and the silicon carbide layers, is a tightly adhering, wear-resistant surface.

The corrosion resistant properties of CVR material, when impregnated with an appropriate resin system, are comparable with those of impervious graphite and may be used in many similar services. A summary of some typical applications can be found in Table 2.

TABLE 2

CORROSION RESISTANCE OF RESIN IMPREGNATED SiC-COATED GRAPHITE PARTS

CHEMICAL	CONCENTRATION WEIGHT, %	TEMPERATURES ° C	(°F)
ACIDS			
ACETIC TO	100	125	(250)
HYDROCHLORIC	25	100	(212)
HYDROFLUORIC	37	85	(185)
PHOSPHORIC	85	BOILING	
SULPHURIC	0-70	BOILING	
SULPHURIC	70-85	170	(338)
SULPHURIC	85-90	149	(300)
SULPHURIC	90-93	1	(160)
SULPHURIC	93-96	ROOM	
ALCOHOLS	ALL	100	(212)
ACETONES, KETONES	ALL	100	(212)
AMINES	ALL	85	(185)
CARBON TETRACHLORIDE	ALL	100	(212)

SUPPORTING DATA:

With an apparently feasible process available, a testing program was initiated which included the following quantitative and qualitative determinations:

Quantitative:

- Laboratory investigation of CVR material abrasion resistance

Qualitative:

- Product Development Program
- Field Test Program

LABORATORY INVESTIGATION OF CVR MATERIAL ABRASION RESISTANCE:

Two types of laboratory tests were developed to determine wear-resistant properties of silicon carbide converted graphite. A sand blasting test was used to determine quickly the relative particulate abrasion resistance of silicon carbide converted graphite vs. commonly used corrosion-resistant pump materials. Materials tested included fiber reinforced plastic, titanium, Type 316L stainless steel, and impervious graphite. A belt sanding test was used to determine the relationship between the thickness of the silicon carbide converted layer and the wear resistance of the part.

The sand blasting test apparatus consisted of a blaster nozzle, air pressure regulator, and test sample holder. Each sample was sand blasted, and the weight loss determined at one minute intervals in this extreme test of particulate erosion. The results of this test are summarized in Figure 2. After five minutes, the weight loss due to erosion of the silicon carbide sample was 2.8%; the FRP sample, 3.3%; the titanium sample, 3.9%; and the Type 316L stainless steel sample, 0.32%. After one minute, the impervious graphite sample indicated 22% weight loss.

The belt sanding test apparatus consisted of a variable speed motor attached to a belt sander and a holder to contain and apply a load to the test sample. Testing with this apparatus was limited to specially prepared samples of CVR material only in order to determine the wear resistance vs. the thickness of the silicon carbide. To determine the depth of conversion, the graphite was removed from samples by oxidation, and the remaining silicon carbide layer was measured. Inadequately converted parts had thin layers of silicon carbide. A correlation between the depth of conversion and wear resistance was observed.

PRODUCT DEVELOPMENT PROGRAM:

Proposed production methods were devised to produce prototype pump parts. The dimensional stability inherent in the CVR process permitted the abrasion resistant parts to be manufactured with close tolerances. Controlled condition laboratory tests were performed for two different operating conditions: 600 GPM, high particle velocity, and 55 GPM, low particle velocity. The test apparatus for both conditions included a 600-gallon tank which was equipped with several agitators to keep the solids in suspension. The test liquid was water containing 3% to 5% foundry sand. Flow rates were monitored with ultrasonic flow meters.

The high velocity tests, which were run for 110 hours, demonstrated that the CVR pump parts were visibly much less affected by abrasive attack than impervious graphite pump parts. Figure 3 illustrates the comparative abrasive attack on the CVR material vs. the impervious graphite material. The abrasive attack on the silicon carbide impeller was the result of the undercutting of the silicon carbide layer. The undercutting can be attributed to weak spots, i.e., localized points of low hardness, or to peripheral areas in which the silicon carbide was deliberately removed prior to testing.

The low velocity tests were run initially for 120 hours. When the parts were examined, the CVR material impeller showed no visible sign of abrasive attack. This impeller was then run as long as possible. After 1200 hours, the CVR impeller showed very little visible abrasive attack. Figure 4 illustrates the comparative abrasive attack on the CVR material vs. the impervious graphite material. Preliminary data from the high velocity tests and from the laboratory investigation led to some minor production changes, which contributed to the improved performance of the low velocity test parts.

Analysis of the results of the development test program indicated the importance of properly designed parts and CVR application. Examination of impellers showed that they are much more subject to abrasive attack in high velocity situations than in low velocity situations. However, this result apparently does not hold true for stationary parts such as volute cases. Figure 5 illustrates the pronounced undercutting around the gasket surface of the impervious graphite volute cases from the low velocity tests.

The results of the development laboratory test program indicated that one may expect an increase of 3 to 10 times the normal service life if one uses properly designed parts with CVR applied to the critical wear areas. The amount of increased service life is dependent upon factors such as particle size and velocity.

FIELD TEST PROGRAM:

The encouraging laboratory and product development program prompted the initiation of field tests of CVR material graphite pumps in several different types of abrasive services. As the field tests were being conducted, the results from earlier laboratory and development tests were used to make design changes on parts. The result was greater relative life in later field test cases.

Typical results of these field tests are summarized in Table 3.

TABLE 3

Type of Service	Flow Rate	Test Duration	Test Results
Ferrous Chloride Plus HCl (20% Solids)	150 GPM	8 Months	CVR Parts tested: Impellers - Service life 1-1/2 times impervious graphite.
Ferrous Chloride Plus HCl (20% Solids)	150 GPM	15 Months	CVR Parts tested: Volute Case - Service life 1-1/2 times impervious graphite. Impellers - Service life 2 times impervious graphite.
50% H_2SO_4 Plus Activated Carbon	250 GPM	8 Months (See Note 1 Below)	CVR Parts tested: Volute Case - Service life 4 times impervious graphite, 8 times FRP. Impeller - Service life 8 times impervious graphite 8 times FRP.
HCl Plus Ferric Chloride Solids Plus Sand and Carbon Particles	40 GPM	6 Months (See Note 2 Below)	CVR Parts tested: Volute Case - Service life 6 times impervious graphite.

Notes:

1. Tests still in progress. No wear on CVR parts to date.
2. Substantiates product development program low velocity test results. Refer to Figure 5. Impellers show no signs of attack; however, the volute case is subject to undercutting at the gasket surface area.

A final example to be noted is the replacement of a severely eroded metallic pump with a CVR impervious graphite pump. Early results from this test indicated greatly reduced wear of CVR impervious graphite compared with the metallic pump.

SUMMARY:

Impervious graphite has been used successfully for several decades in corrosive environments.

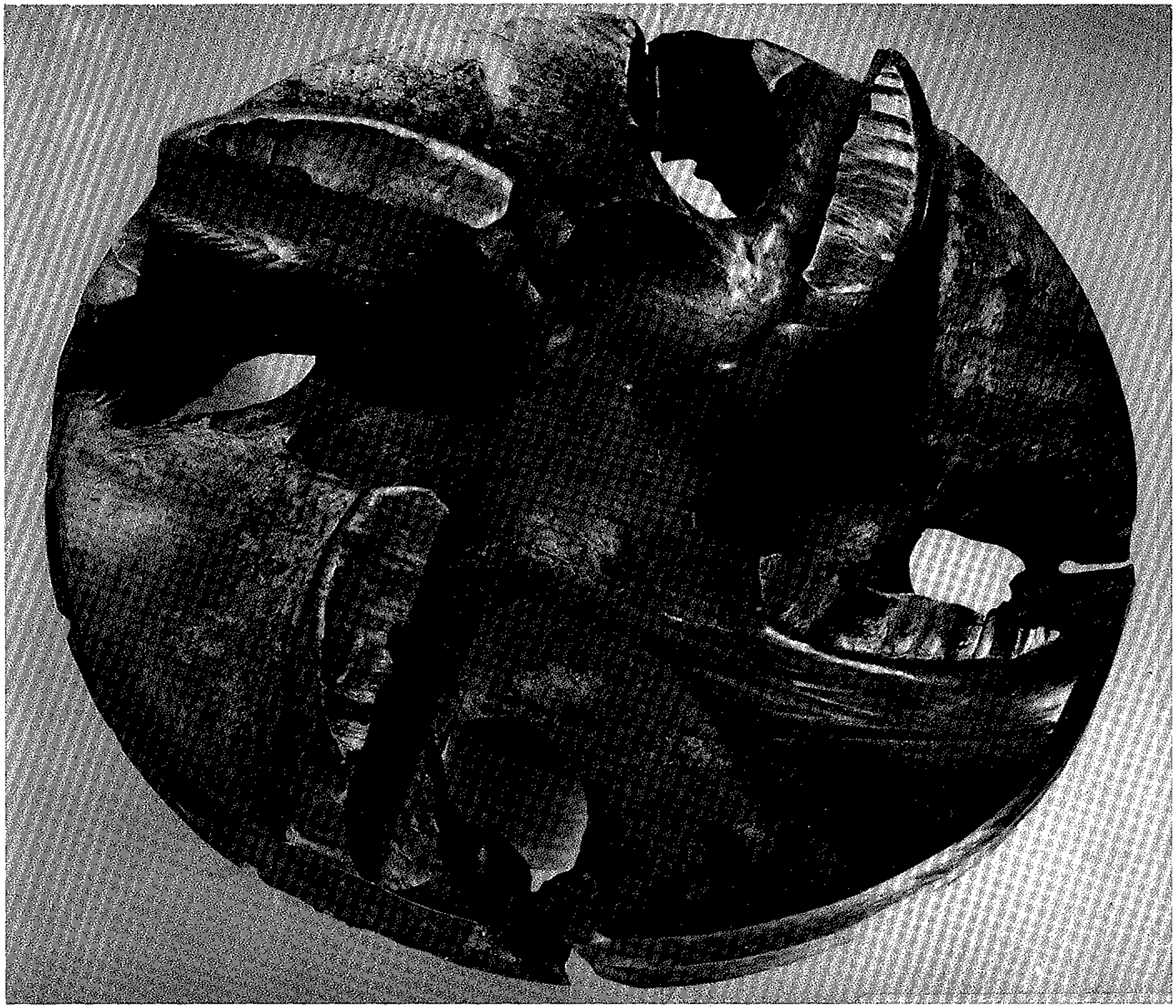
The marriage of a CVR process silicon carbide to impervious graphite parts makes possible the use of this corrosion-resistant material in severely corrosive-abrasive applications.

Depending upon the severity of the service conditions, the life of impervious graphite parts can be extended by 3 to 10 times.

The CVR process described in this paper is by no means the only method of producing acceptable silicon carbide - impervious graphite parts.

REFERENCES:

1. Silicon Carbide Coated Graphite: By R. Robert Paxton and Scott Brown, Pure Carbon Company.



Particulate Erosion on
Impervious Graphite Impeller

Figure 1

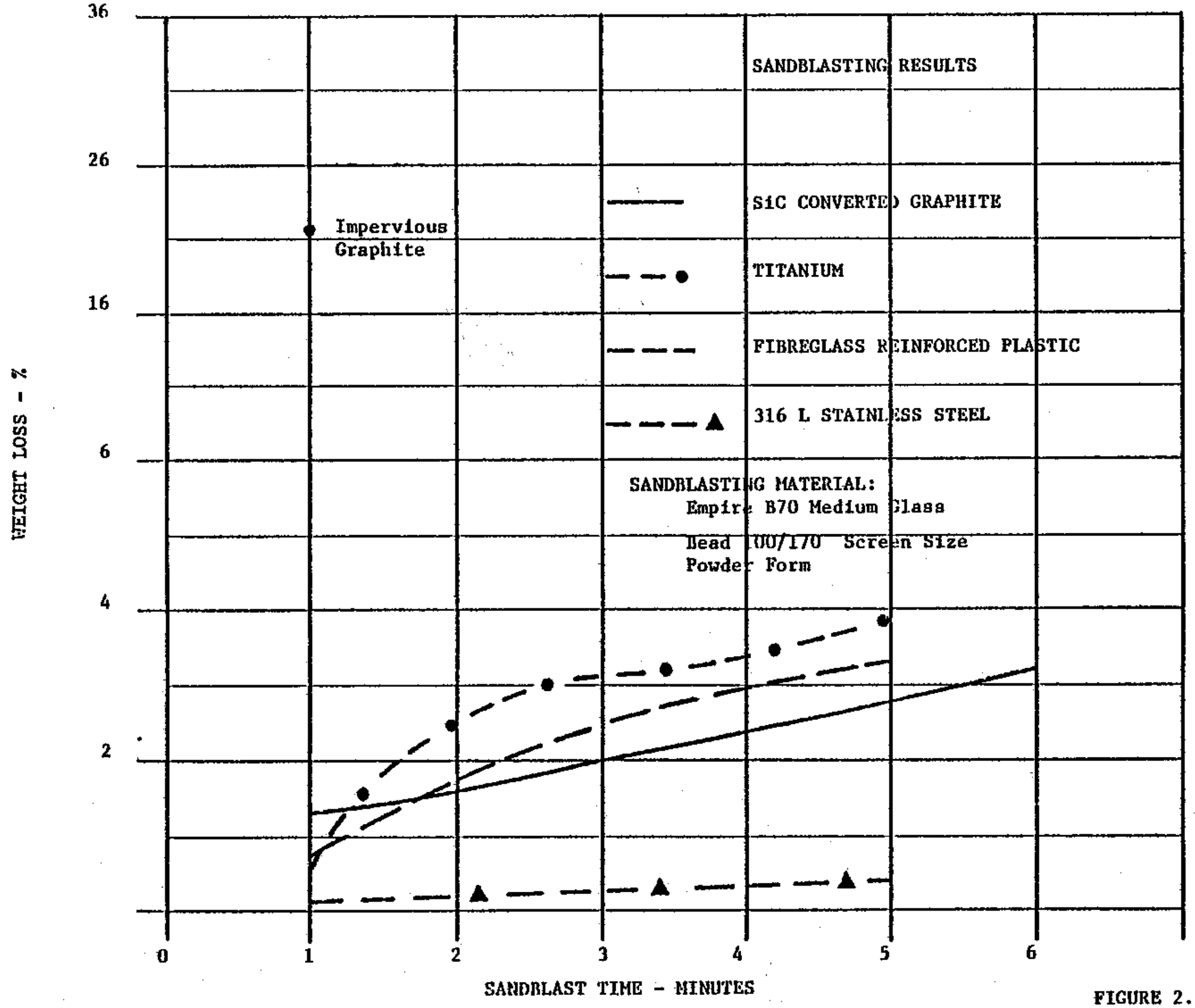
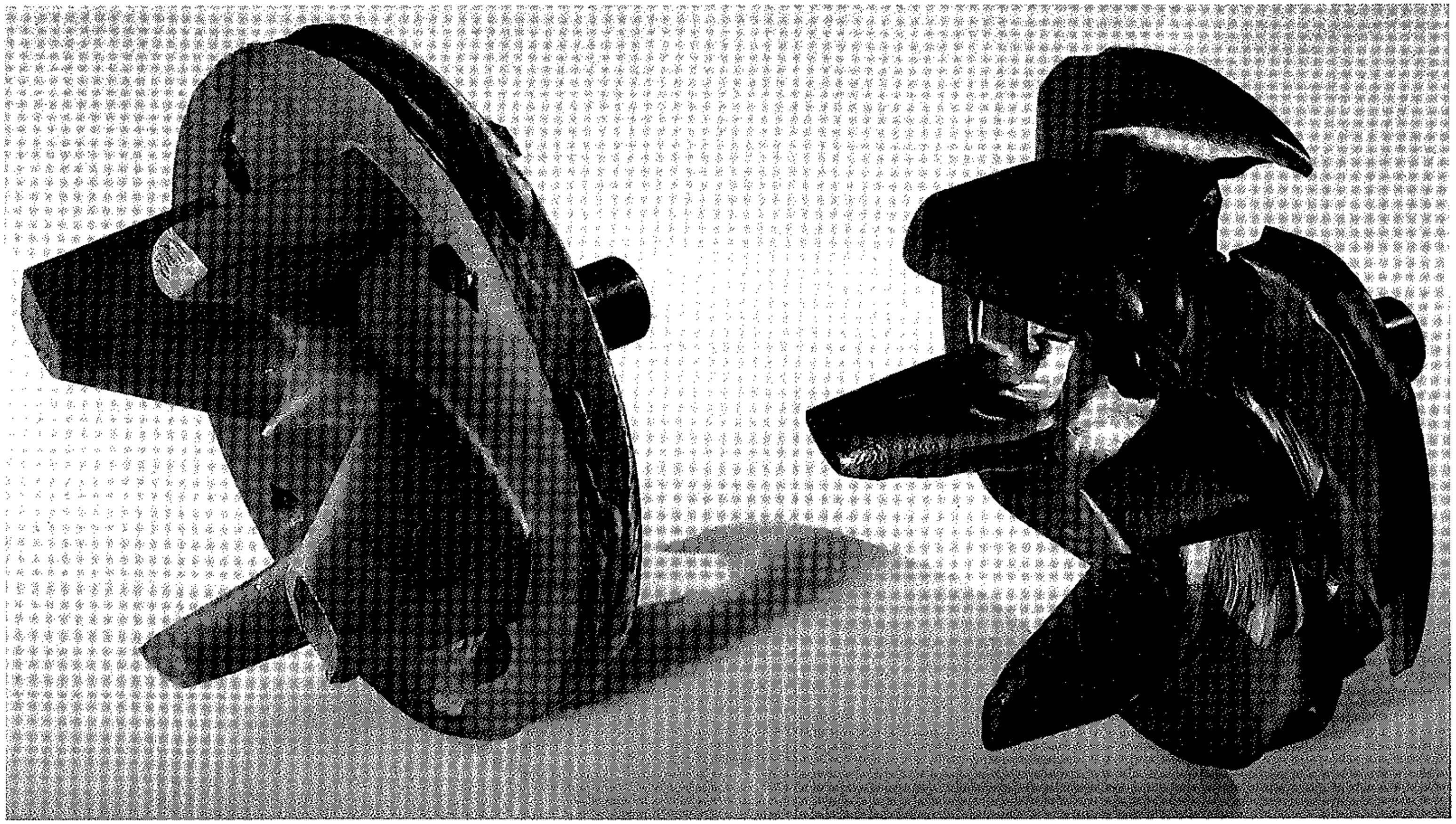
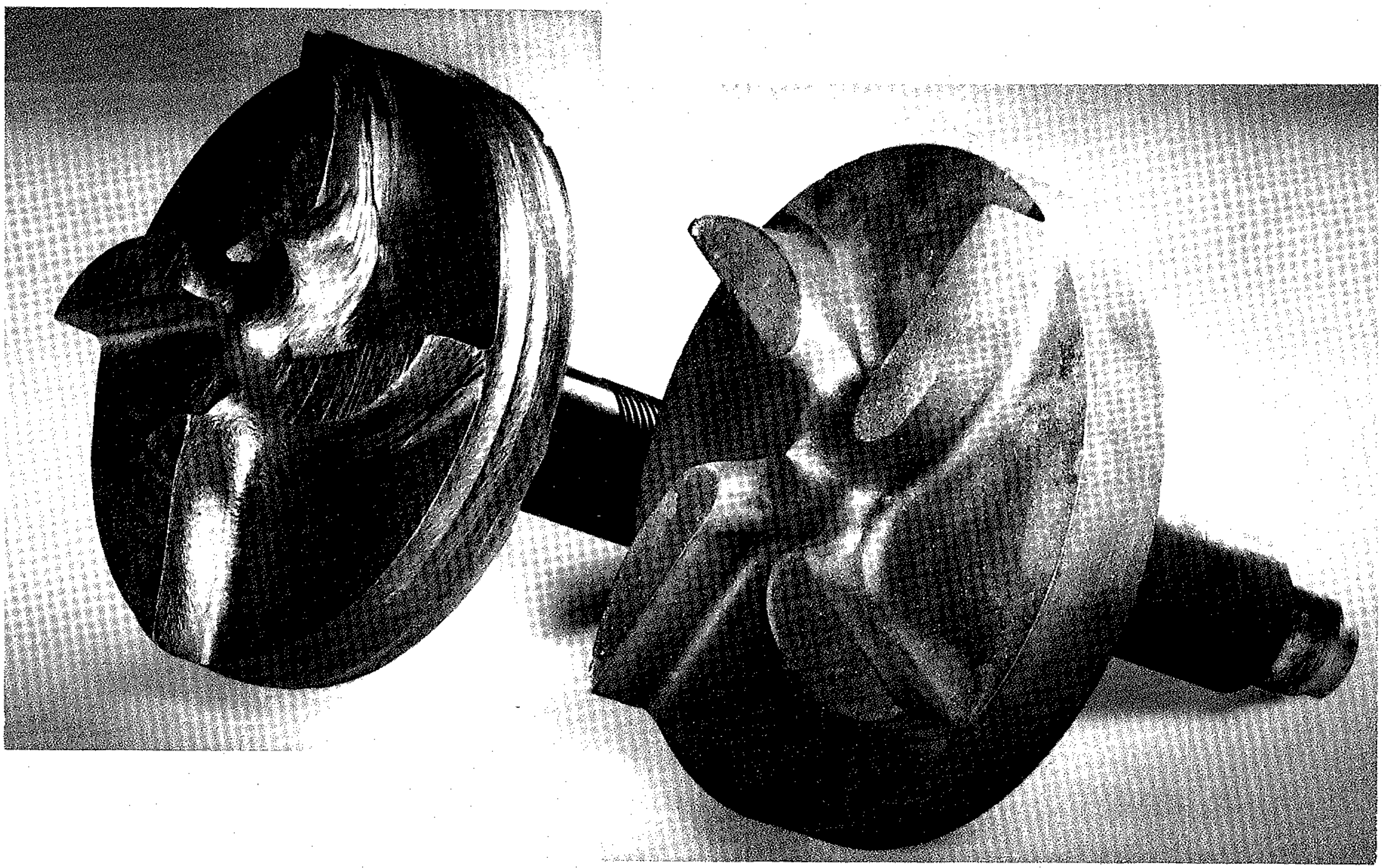

SANDBLASTING RESULTS
SiC CONVERTED GRAPHITE
TITANIUM
FIBREGLASS REINFORCED PLASTIC
316 L STAINLESS STEEL
SANDBLASTING MATERIAL:
Empire B70 Medium Glass
Bead 100/170 Screen Size
Powder Form
Impervious Graphite
WEIGHT LOSS - %
36
26
16
6
4
2
0
1
2
3
4
5
6
SANDBLAST TIME - MINUTES

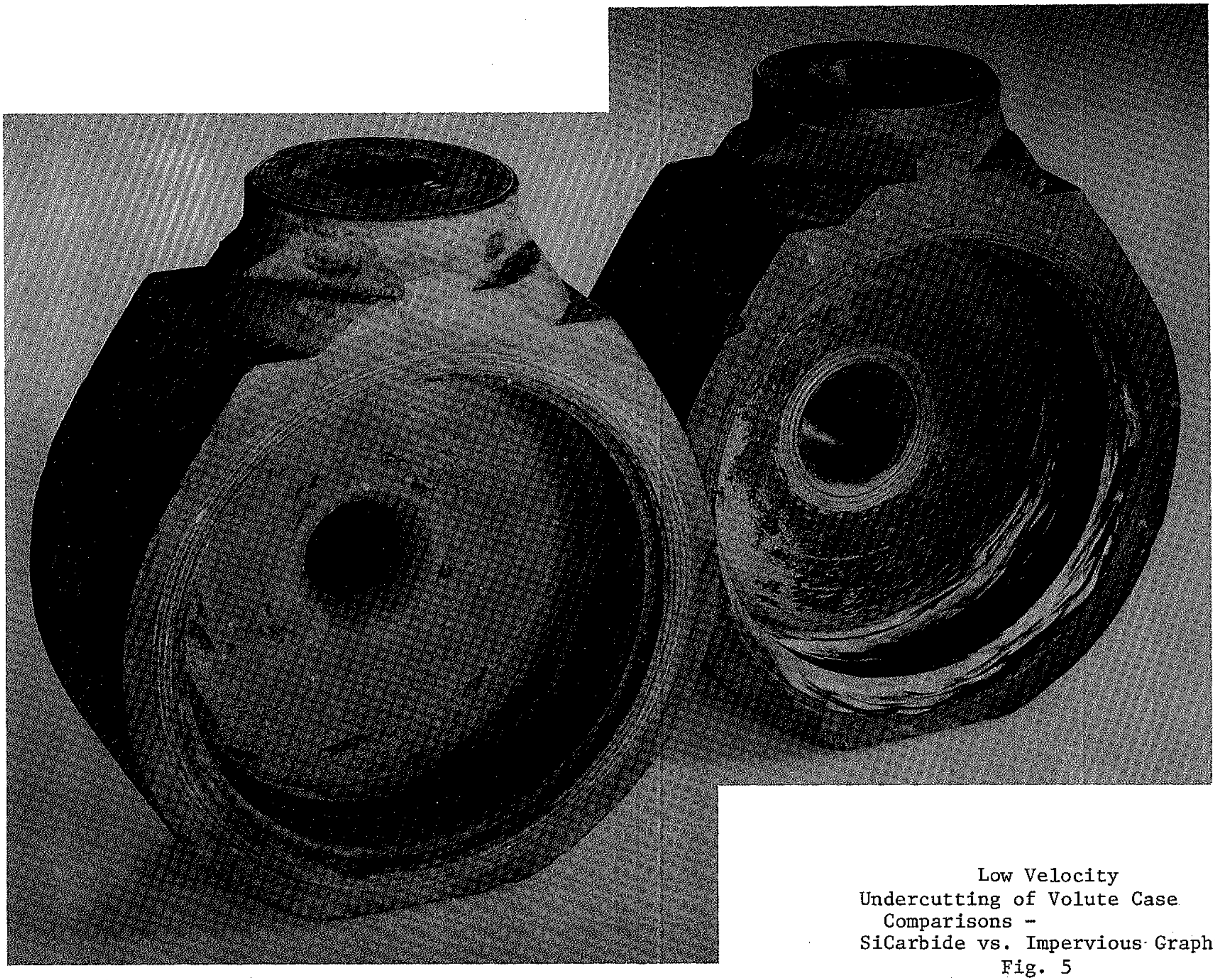
FIGURE 2.



High Velocity Test Comparisons
SiCarbide vs. Impervious Graphite
Impeller
110 hrs.   3-5% Foundry Sand
Fig. 3



Low Velocity Test Comparisons
Impervious Graphite vs SiC Impeller
3-5% Foundry Sand
120 Hrs. 1200 Hrs.
Impervious Graphite SiC Impeller
Impeller Fig. 4



Low Velocity
Undercutting of Volute Case
Comparisons -
SiCarbide vs. Impervious Graphite
Fig. 5

NOTES