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A Characterization of Alternative Tooling Materials Using Impact Abrasion Testing

Michael C. Formanek
University of Northern Iowa

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Abstract

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Of the materials tested three were included in the ceramics group. These materials demonstrated average wear resistance. The percent weight loss ranged from 1.290% to 2.325% over a twelve hour period of time. Two of the three materials demonstrated that they could achieve a weight loss under the acceptable standard of 1.6% established in a previous study done by Maier and Wallace. (1977)

The polyurethane elastomer group consisted of three materials. One material RP644 was tested twice. This was done to see what different curing times and temperatures have on the material. This group had an average weight loss ranging from . 9540% to 1.1816% over a twelve hour period. The relative low weight loss of this group suggests that it should be considered for use in pattern and corebox construction.

In addition to the nonmetallics there were five metallic materials evaluated. Among these was the benchmark material, Class 40 gray iron. All of the metallics performed as expected. The steels performed better than the gray iron, which tested better than the aluminum samples. These materials were chosen on the basis that they are being used as tooling materials and have not been tested previously.

A CHARACTERIZATION OF ALTERNATIVE

TOOLING MATERIALS USING

IMPACT ABRASION TESTING

A Research Paper

Submitted

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Michael C. Formanek
University of Northern Iowa
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Dr. Ahmed Elsawy, Graduate Faculty (Second Reader)	12-06-95 Date
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ABSTRACT

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INTRODUCTION

In the foundry industry a large percentage of the cost of castings comes from the cost of producing tooling for patterns and coreboxes. Metallic tooling has historically been the first choice for pattern makers. With new materials being developed, foundries are looking for cheaper alternatives to metallic tooling. This study focused on the wear resistance of new materials developed in the past few years. These materials are either being used or being considered as tooling materials. It also evaluated the wear resistance of materials that have been in use for some time. This study used criteria established by Vondra (1992) in comparing the materials to gray iron and assigning them a wear factor. This wear factor can be used to predict the life of the tested materials as compared to the gray iron sample.

STATEMENT OF THE PROBLEM

Pattern wear has been a problem as old as the industry itself. Helzer and Vondra stated in 1993, "The issue of dimensional tolerance and pattern wear with today's modern machine tools and the need for casting processes that are capable of reproducing parts that are within those dimensional tolerances is more critical than ever before." Pattern wear will never be eliminated due to the fact that the most common molding material used in foundries is sand. Sand by nature is very abrasive and causes wear by many mechanisms. Therefore, the materials themselves must improve in order to exhibit better wear resistance.

The most common tooling material for foundries is gray iron. This material has provided good wear resistance in the sand and environment. It is used in both patterns and coreboxes. Gray iron is easily machined to achieve high tolerances and is also resistant to chemical agents used in pattern releases and mold sprays. The major disadvantage to this tooling material is that it is costly and requires a lot of time to produce.

The combination of being expensive and the long lead times have forced some foundries to look at nonmetallic materials to replace metallics as their main tooling media. Alternative tooling materials are easily produced and are inexpensive when compared to metallics. These qualities make many of them look like desirable replacements in the tooling application.

To address the tooling problem, we must find materials that are suitable for foundry tooling applications. These materials need to be evaluated on their ability to resist abrasion by sand to judge their effectiveness. In addition to the new materials there is a need to compare existing tooling materials. This evaluation will implement a wear factor already developed from a previous study (Vondra, 1992) to maintain a sense of continuity. This wear factor is used to predict the tool life of tested materials as compared to a standard.

REVIEW OF THE LITERATURE

Wear analysis of alternative tooling materials is not a new subject. The most highly used test was developed by Gowens (1966). His test was the first to recognize the need to simulate the abrasive conditions that most foundry environments contain. This test was designed to simulate the impact that a core blower produces when it blows bonded sand to make cores. In his test specimens were placed in a high speed impeller inside a glass drum. The drum was rotated slowly to allow the partially bonded sand to cascade around the specimens. The specimens were placed at a 45° angle to form the blades of the impeller. The specimen size was 1 x ½ x 1/4 in. The test was conducted in three four hour segments. Each sample was weighed before and after testing. The specimens in this test consisted of three metallics and six non-metallics.

In 1977, Maier and Wallace modified this test to insure reproducible results. Instead of using partially bonded sand, an unbonded subangular silica sand with a AFS GFN of 69 was used. The use of unbonded sand insured that the sand would flow freely and that the maximum amount of abrasion could occur. The speed of the drum was optimized to a speed of 82 rpm. This speed was determined to maximize the amount of sand impacted per unit time testing. Sand was also changed after each four-hour test. This insured a uniform wear on the materials for each test. Materials used in this test consisted of 15 metallics and nine non-metallics. From this test they determined that a 1.6% weight loss was acceptable for use as tooling materials.

Helzer in 1988 conducted a study using the same procedure of the previous researchers. In his test a sand with an AFS gfn 58-64 was used. Another difference between his test and the Maier and Wallace tests were the types of materials tested. The majority tested in Helzer's were non-metallics while Maier and Wallace had focused on metallic materials. This study grouped the materials into four major groups: metallic pattern materials, plated pattern materials, non-filled polymers, and filled polymers. His conclusion stated that each group's performance varied but within the group similar materials behaved in a comparable manner. This was the first strong investigation of alternative tooling materials.

Since Helzer's experiments there have been some developments in impact abrasive testing. Ciba-Gigy developed new testing equipment that is capable for testing more samples at one time. They performed tests using some of the same materials previously tested. (Hoge, 1991) They concluded that they achieved a strong correlation to conventional impact abrasion testing. However, upon analysis of the data collected it is this author's opinion that these results should not be used due to the fact the tests performed did not follow the same procedure established by previous abrasion tests.

The most recent and comprehensive study done was in 1992 by Vondra. This study evaluated 34 materials using Helzer's procedure. The study was conducted to establish a decision making tool that foundrymen could use in choosing a pattern material. A wear factor was created based on the percentage weight loss test data. The benchmark of this factor was Class 30 gray iron. From this study the percentage weight lost by a material was divided by the percentage weight lost of class 30 gray iron. The number derived was considered the wear factor of that material. This study assumed that all materials would experience some wear due to the impact abrasion. The wear factor was then used to predict the life of tested material.

Materials with similar properties were grouped together to analyze how their group performed as a whole. Besides the wear factor, this study used Maier and Wallace's conclusion stating that 1.6% weight loss is acceptable pattern wear in judging whether the tested materials performed to an acceptable standard.

From this review of literature it is apparent that there has been very little published research done on the abrasion resistance of tooling materials. From the previous studies, impact abrasion testing appears to be the most common means to evaluate wear resistance. Of the five studies listed four used the same procedure to establish a material's ability to resist wear. The most common measurement in all the studies was percentage weight loss.

As more materials are being introduced there is a need to continue this research. It is evident that all materials being used or considered for use in pattern or corebox construction should be evaluated on their wear resistance. This research will help in the decision making process involving the choice of tooling materials.

TEST MATERIALS

The samples tested for this study were supplied by manufactures of tooling materials and pattern companies that use them. Most of the samples arrived in the desired size specifications needed for the test. Some samples were constructed at the University following the manufacturers directions. Some of the materials tested are not currently being used in the foundry industry but are being considered for use. Five metallics were tested. These materials are already being used in pattern and corebox construction but have not have been evaluated for their wear resistance. The following is a description of the materials and when applicable, how they were prepared.

Polyurethane Elastomers

Uralite 3515 form Hexcel. This material is an amber colored Polyurethane elastomer. It is made up of two components (part A and part B). It has a 70 Shore D hardness. Mixing ratios are Part A 100 and Part B 60 by weight. It usually applied by casting onto a prepared surface. The material should be of fairly consistent thickness and should not be more than 0.12 inches thick. This material was cured at room temperature (77° F). It can be used for coreboxes and patterns.

Uralite 3517 from Hexcel. This material is an amber colored polyurethane elastomer. It is made up of two components (part A and part B). It has a 60 Shore D hardness. Mixing ratios are Part A 100 and Part B 50 by weight. It is usually applied by casting onto a prepared surface. The material should be of fairly consistent thickness and should not be more than 0.12 inches thick. This material was cured at room temperature (77° F). It can be used for coreboxes and patterns.

RP 6444 RT from Ciba Gigy. This material is an amber colored polyurethane elastomer. It is made up of two components (part A and part B). It has a 60 Shore D hardness. Mixing ratios are Part A 100 and Part B 60 by weight. It is usually applied by casting onto a prepared surface. The material should be of fairly consistent thickness and should not be more than 0.12 inches thick. This material was cured at room temperature (77° F). It can be used for coreboxes and patterns.

RP 6444 HC from Ciba Gigy. This material is an amber colored polyurethane elastomer. It is made up of two components (part A and part B). It has a 60 Shore D hardness. Mixing ratios are Part A 100 and Part B 60 by weight. It usually applied by casting onto a prepared surface. The material should be of fairly consistent thickness and should not be more than 0.12 in. This material was cured for 16 hours at 80 ° C. It can be used for coreboxes and patterns.

Artificial Modeling Material

Polyboard 222 from Fiber Resin Corp. This material is shaped using the same processes as wood. It is easily machined and has excellent dimensional stability. The material has a 65-Shore D hardness. It is used only with prototype and short production runs. It can be used for patterns but is an unlikely candidate for coreboxes.

Metallic Tooling Materials

American Iron and Steel Institute (AISI) D2 Tool Steel. This high carbon steel contains 1.5% carbon and 12% chromium. It is usually heat treated to achieve a hardness range of 54 to 61 HRC. (Unterweiser, 1982) This steel has a high resistance to softening. This characteristic is desirable when it is critical to maintain tolerances in tooling.

AISI H13 Tool Steel. This steel is very tough and when annealed can achieve a range of hardness of 192-229 HB. It is a low carbon steel (0.35%) and is widely used for tooling, especially in permanent mold, because of its excellent wear characteristics. (1982)

Class 40 Gray Iron. This is the benchmark material for this study. A typical Class 40 Gray Iron has a tensile strength of 40,000 psi and a BHN of 235. It is a harder and is stronger than the benchmark material, Class 30 used in a previous study. These characteristics make it more difficult to machine than Class 30. However, it is a commonly used tooling material. It is used when the tooling will be subjected to greater than normal stresses.

Aluminum Association 319 Aluminum. This is the most common of the aluminum alloys used in pattern construction. It is alloyed with 3.0-4.0% copper and 5.5-6.5% silicon. It typically has a Brinell hardness of 70 and an ultimate tensile strength of 19,000 p.s.i. (AFS, 1993) It is easily machined and is a simple casting alloy.

Aluminum Association 356 Aluminum. This alloy contains 6.5-7.5% Silicon and 0.2-0.45% Magnesium. This alloy typically is heat treated after casting. It has a

Brinell hardness of 75 and an ultimate tensile strength of 38,000 p.s.i. (1993) This alloy is used when the molding process requires the tooling to withstand high pressures.

Ceramic Materials

KZ Ceramic 8472 30%. This a new castable ceramic made up of three components. It is 30% ceramic and is backed up with fiberglass for strength. The surface is coated with a hardener. It has a Barcol hardness of 75. Mixing and chemical composition data is confidential to the manufacturer. It is being investigated for pattern and corebox applications.

KZ Ceramic 8151 30%. This is a new castable ceramic made up of three components. It 30% ceramic and is backed up with fiberglass for strength. The surface is coated with a hardener. It has a Barcol hardness of 75. Mixing and chemical composition data is confidential to the manufacturer. It is being investigated for pattern and corebox applications.

Black KZ Ceramic Gel Coat. This is a new castable ceramic that contains 75% ceramic material. It has a Barcol hardness of 75. Mixing and chemical composition data is confidential to the manufacturer. It is being investigated for pattern and corebox applications.

TEST PROCEDURE

The standards used for testing were established from Vondra et all. The machine used was developed and constructed by Gowen (1966) and is the only one in existence.

The testing equipment used in the research uses a Pyrex drum filled with five pounds of sand. A fixture holding two test pieces is placed inside the drum. See figure 1. The drum is rotated at 82 rpm causing the sand to cascade onto the fixture holding the test pieces. The fixture rotates in the same direction as the drum at approximately 1400 rpm. The test pieces are held at a 45° angle to cause an impeller effect with the sand. See figure 2. This configuration was developed in Gowen's study (1966) and has been used in all following tests.

Figure 1

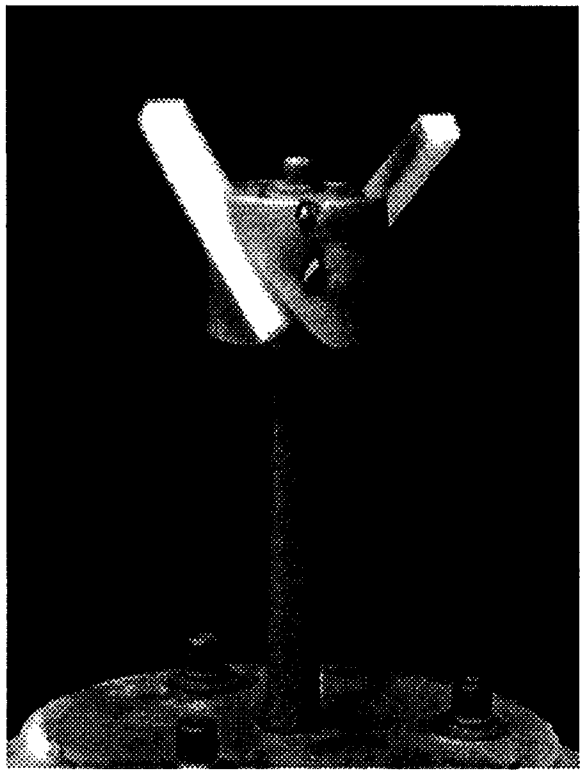

Figure 2

Each piece was tested at three four-hour cycles. Two specimens of different material with similar weight were tested at a time. Two samples of each material were tested and the resulting percentage weight loss numbers averaged. The weights were recorded before and after each cycle using an Ohaus GT 480 scale. This scale is a 454-gram scale and is calibrated every six months in accordance with NIST #732/246690-#523/240932 standards.

The sand used for the test was 58-62 GFN subangular to round silica sand and was replaced after each cycle. This is to insure that any fractured grains were eliminated and that the same level of abrasiveness was maintained throughout the test.

SUMMARY OF RESULTS

Of the materials tested three were included in the ceramics group. These materials demonstrated average wear resistance. The percent weight loss ranged from 1.290% to 2.3246%. See Table 1 Appendix A. The Black KZ Ceramic Gel Coat was the only material that was not backed with fiberglass and displayed unacceptable wear. The rest of these materials are being considered for use as tooling materials and demonstrated that they could achieve a minimum weight loss under the acceptable standard of 1.6% established in previous studies.

The Polyurethane elastomer group consisted of three materials. This group had an average weight loss ranging from .9540% to 1.1816%. See Table 1. One material, RP644, was tested twice to ascertain what different curing times and temperatures during construction have on the material. The material that was heat cured performed slightly better than the material cured at room temperature.

One artificial modeling material was tested. Polyboard 222 had a percent weight loss of 6.400%. See Table 1. This material exhibited the highest wear rate of the test specimens. This was to be expected since this material is commonly used to make prototype tooling and is not designed as a production tooling material.

Five metallics were tested in this study. The results corresponded with the metallics that were previously tested. The steels performed better than the benchmark material Class 40 gray iron. The Class 40 out performed the A319 and A356 Aluminum samples. The Class 30 tested in previous study had a percentage of wear of 0.1160 while the Class 40 had a percentage of wear of 0.1785. This may be explained by the differences in hardness. The softer material (Class 30) may give more as opposed to the class 40, and this may be reflected by the hardness.

CONCLUSIONS

From the data collected it appears that there is still no non-metallic material that can replace gray iron from a wear resistance standpoint. All of the materials performed as expected. Only in the ceramic group has there been improvement in wear resistance compared to a previous study the ceramics tested achieved a percent weight loss of 2.4957. (Vondra, 1992) The KZ Ceramic 8151 and 8472 were able to achieve a percent weight loss of 1.325 and 1.290 respectively. This was the only group that performed better than previous tests.

In Maier and Wallace's study 1.6% was established as the acceptable weight loss for tooling material. In this study all of the polyurethane elastomers met this criteria. The materials not meeting this standard are designed for prototype materials. Therefore, they were not expected to perform like the other materials. All materials that are used or are being considered for use as tooling materials performed to this standard.

The wear factor established in this study is based on percent weight loss. Table 1 in lists the percent weight loss and the corresponding wear factor. The wear factor indicates the number of tools required of a material to equal the wear resistance of Class 40 gray iron. For example, it would take 6.62 tools of Uralite 3515 to equal the wear resistance of one Class 40 gray iron.

RECOMMENDATIONS

Based of this findings of this study it is recommended that the tooling materials that exhibited a weight loss under 1.6% should be considered as tooling materials in pattern and corebox construction. The materials that showed greater wear may have potential as tooling materials in prototype and short run production

Further research is recommended to:

1. conduct a cost comparison study to analyze the expenses of implementing nonmetallic tooling versus metallic tooling;

2. repeat the tests conducted in this study with new materials once they are available from the manufacturer;

3. study the effects of foundry chemicals on nonmetallic tooling;

4. conduct a study that will test materials in a true foundry setting to evaluate whether or not that impact abrasion testing is accurately predicting tool life. This is currently being undertaken at the direction of the AFS Pattern and Tooling Division 7 committee.

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APPENDIX A

WEAR ANALYSIS TABLE

Table 1.
Wear Analysis.

Material	Percent Weight Loss	Wear Factor
Polyboard 222	6.400	35.86
Black KZ Ceramic Gel Coat	2.325	13.03
Uralite 3517	1.366	7.65
KZ Ceramic 8151	1.325	7.42
KZ Ceramic 8472	1.290	7.23
Uralite 3515	1.182	6.62
RP 6444 RT	0.991	5.55
RP 6444 HC	0.954	5.34
A319	0.623	3.49
A356	0.272	1.52
Class 40	0.785	1
H13 Steel	0.155	0.69
D2 Steel	0.114	0.64

APPENDIX B

LETTER FROM THE AMERICAN FOUNDRYMEN'S SOCIETY

AMERICAN FOUNDRYMEN'S SOCIETY, INC.
publishers of *modern casting*

CAST METALS INSTITUTE, INC.

11/09/95

Mr Michael C Formanek
Univ of Northern Iowa
Metal Casting Center
Cedar Falls IA 50614-0178

Subject: 100th Casting Congress & CastExpo - April 20-23, 1996,
Philadelphia, Pennsylvania, USA

Dear Mr Formanek

We have received the manuscript entitled:

A Further Evaluation of Wear Analysis of Selected Tooling Materials Using Impact Abrasions Testing

The paper has been assigned **No. 96-105** . Please refer to this number in any future correspondence concerning this submission. Additionally, please check the spelling of your name, company, and paper title displayed in this letter. This information will be used **exactly** as it is shown for promotions and publications. **Notify us of any errors immediately.**

AFS policy requires that the paper be peer reviewed to determine its suitability for presentation and/or publication. This manuscript will be sent to the appropriate Program and Papers Committee for reviewer assignment. When the review process is complete (after February 1st), we will notify you concerning the status of your manuscript.

Thank you for your contribution to the AFS Casting Congress. If you have any questions, please contact me.

Sincerely,

Robert E. Eppich
Casting Congress Coordinator

(acknowlg)