

Advances in the Production and  
Use of

# STEEL

with IMPROVED  
INTERNAL CLEANLINESS

John K. Mahaney, Jr.

EDITOR



STP 1361

**STP 1361**

***Advances in the Production and  
Use of Steel with Improved  
Internal Cleanliness***

*John K. Mahaney, Jr., editor*

ASTM Stock #: STP1361



ASTM  
100 Barr Harbor Drive  
West Conshohocken, PA 19428-2959

Printed in the U.S.A

## Library of Congress Cataloging-in-Publication Data

Advances in the production and use of steel with improved internal cleanliness / John K. Mahaney, Jr., editor.

(STP : 1361)

"ASTM stock #: STP1361."

Papers from a symposium held in Atlanta, Ga., May 4-7, 1998.

Includes bibliographical references and index.

ISBN 0-8031-2605-0

1. Steel—Inclusions. 2. Steel—Refining. 3. Steel castings.

I. Mahaney, John K., 1941- . II. Series: ASTM special technical publication; 1361.

TS300.A34 1999

672.2-dc21

99-13369

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# Foreword

This publication, *Advances in the Production and Use of Steel With Improved Internal Cleanliness*, contains papers presented at the symposium of the same name held in Atlanta, Georgia, on May 4, 1998. The Symposium was sponsored by ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys. The symposium chairman was John K. Mahaney, Jr., LTV Steel.

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# Overview

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As ASTM Committee A-1 reached 100 years of service to industry, consumers, and the government, the Committee wanted to reflect on the status of a major source of problems in steel. From earliest times, the presence of nonmetallic inclusions has been a major source of problems and failures. Failures due to inclusions have been seen in major structures and boilers as well as the inability to successfully form material into usable shapes and parts. The Committee sought to determine the status of the state of the art of inclusion identification and prevention, as well as the relative status of different parts of the industry in the attempt to produce material with improved internal cleanliness.

The papers presented in this book cover areas from bearing steels to castings. The various authors clearly show that level of inclusion identification and control through processing improvements is greatly dependent upon the sector of the industry. The level of inclusions desired in bearings is several orders of magnitude from the majority of the casting industry. At the same time, manufacturing methods such as continuous casting and other tonnage industry methods are not available in the discrete steel and iron casting segments of the metal melting industry.

The papers in the Special Technical Publication show the state of the art in inclusion identification, prevention, and understanding of the deleterious effects of those inclusions. Products covered include bearing steels, high-strength plates, steel castings, stainless steel medical implants, and test methods to determine the presence and effect of nonmetallic inclusions in the steel products. The papers emphasize the effect on the products rather than manufacturing methods.

The authors of the papers in this publication include researchers and practitioners from the United States, Europe, and Asia. The companies and research institutions represented by those authors include The Timken Company, The University of Alabama at Birmingham, the Steel Founders Society of America, SKF Engineering & Research Center, Ovako Steel, Thermax Ltd., Synthes (USA), and Bethlehem-Lukens Plate Company.

## **Bearing Steels**

The presence of even very small inclusions are clearly shown in the papers presented here to adversely affect performance in bearings. The problem is shortened life of the bearing. The related problems with bearing failure include major machine failures. One must be able to detect the presence of inclusions and then determine the source of such nonmetallics and develop methods to either prevent the formation of such materials, typically oxidation products, or if those deleterious materials are formed, proper treatment of the molten product to minimize or prevent the occurrence of inclusions in the product made from the molten metal, generally an ingot.

Within the bearing community, the emphasis on minimizing inclusions has been successful to the extent that the conventional methods of detection are no longer sufficient. The researchers recognize that one can not eliminate what one can neither detect nor identify. They further recognize the effects of extremely small inclusions on bearing life and thus the performance of the product.

However, one must first be able to determine the presence or absence of inclusions to understand the performance issue.

A method using ultrasonic methods to determine internal cleanliness of the material and then to relate such findings to bearing life is described in the paper by Eckel, Glaws, Wolfe, and Zorc of The Timken Company. Beswick, Gabelli, Ioamides, Tripp, and Voskamp presented information on bearing life models that take into account the hardness or strength of the bearing and the effects of the very fine inclusions "micro-inclusions" that are the result of today's production technology for bearing steels. Recognizing that production methods have to be understood and controlled in order to achieve the cleanliness levels necessary for the Beswick et al. model, the work by Lund and Ölund examine how the various steel making and processing operations can affect internal cleanliness and thus bearing life.

### **Stainless Steels**

A major use of stainless steels has been for various implants in the human body to replace body parts damaged for some reason. The human body is not a particularly friendly place for a foreign object, such as an implant. Inclusions act as corrosion initiation sites and thus lead to rapid deterioration of the implant and thus the effectiveness of that medical device.

While oxides are the primary inclusion forms of concern in many sectors of the industry, the medical implant concerns also include manganese sulfides, carbides, delta ferrite, and other secondary phases as sources of corrosion cells and thus problems with implant life. Disegi and Zardiackas review developments in this area.

### **Steel Castings**

While bearings and many other forms of steel can be handled in ways to avoid contact with air, continuous casting and bottom pouring for example, in the casting industry, numerous castings are by necessity poured in air from the ladle into the mold. This action, along with turbulence in the pouring stream and within the mold, as well as mold design, can lead to the trapping of large non-metallic inclusions at the surface of the casting. These inclusions then lead to machining failure during processing of the castings. Blair, Monroe, and Griffin review the numerous technique and processing modifications that have been studied in this segment of the industry to minimize what they term "macroinclusions." The casting industry must adapt practices in use in other portions of the iron-and-steel-making business to their industry, which is very different in scale and manufacturing methods from the bearing, bar, and flat-rolled sectors of the industry. Developing an understanding of the causes of inclusion problems is fundamental to resolving the problems. Blair et al. present evidence of how the proper application of various techniques can significantly improve the product by preventing the very large inclusions.

### **Steel for Plates**

Steel plates are a fundamental building block of American industry. The strength and load-bearing capabilities of structural steel plates are critical to the construction of everything from major office buildings to offshore oil platforms. Wilson describes how improved internal cleanliness has improved material toughness, increased ductility, and improved the fatigue life of structures. He also notes the interactions that can take place between and among production variables. Such interactions can affect the reliability of inclusion control during steelmaking and must be understood and controlled to prevent the development of less than desired properties in the finished product.

Steel plates are also used for pressure vessel applications, and many heads for such vessels are formed using spinning techniques in the heavier thicknesses. The development of lamellar separations

at mid-thickness is not desirable. Dutta, Chandawale, and Vanchinath have developed a test method to determine the tendency of materials to crack internally during spin forming. They emphasize the importance of low levels of chemical segregation and lowering sulfur content as ways of improving the performance of materials when spun into tank heads.

## Conclusions

Steel cleanliness means many things to many people. The levels of internal cleanliness or freedom from inclusions achieved by the bearing industry are clearly well beyond that associated with castings. On the other hand, the manufacturing methods available to the casting industry make the application of bearing-type manufacturing techniques very difficult, and other manners of inclusion prevention and control must be developed.

Improvements in performance of materials are the result of continuing efforts to understand why failures and problems occur. The bearing industry has greatly improved bearing life through the control of internal cleanliness and seeks continued life spans for the bearings. The casting industry is achieving reductions in material and time losses due to inclusion problems. The absence of such large inclusions also has to improve the life of those castings, especially in fatigue situations. A better understanding of inclusions has provided medical implants with improved corrosion resistance and thus better life. Buildings and pipelines with improved performance, and thus far fewer failures and other problems, have resulted from improved internal cleanliness in steel plates for structural and pressure vessel applications.

The need to continually improve the products used by all of us means that the drives to improve internal cleanliness are only beginning. The presence of any nonmetallic particle in the steel matrix can be the initiation site for failure. Our efforts to minimize such problems have resulted in great improvements in bearings, structural steels, and medical implants, to mention a few products. However, further improvements will come but only with a firm understanding of where we are today. The papers contained in this Special Technical Publication provide an excellent base for such understanding and for future improvements in the products we all use.

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ISBN 0-8031-2605-0