Fracture Resistance of Aluminum Alloys
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CHAPTER 1

Introduction

1.1 Synopsis

THE TEST METHODS and criteria used to evaluate the fracture characteristics of aluminum alloys are reviewed, and a substantial amount of representative test data for individual lots of aluminum sheet, plate, forgings, extrusions, and castings are shown for a wide variety of aluminum alloys, tempers, and products at room, subzero, and elevated temperatures. The significance and use of various measures of toughness are discussed, and the more valuable fracture indexes are identified.

From the tensile test, elongation and reduction in area provide a measure of the behavior of materials in very simple stress fields but offer only a broad indication of fracture behavior. Notch toughness, as measured by the notch-yield ratio, is a useful relative measure of the capabilities of materials to deform plastically in the presence of stress-raisers. Tear resistance, as measured by unit propagation energy from the tear test, provides a meaningful measure of relative resistance to either slow or unstable crack growth. Fracture toughness, based upon fracture-mechanics concepts, defines the conditions for unstable crack growth in an elastic-stress field; it is a direct measure of toughness in that it provides structural designers with specific guidance as to how to avoid “brittle” catastrophic fractures. The fracture mechanics approach is most useful for high-strength aluminum alloys but has restricted applicability to many broadly used commercial alloys, most of which have great ability to deform plastically at crack tips and absorb energy. Unstable crack growth in elastic-stress fields is rarely encountered for high-strength aluminum alloys.

Of the structural aluminum alloys, the 5*xxx* series provide the most attractive combination of strength and toughness for critical applications such as liquefied natural gas storage and transportation tankage. Among the higher strength alloys, premium toughness alloys such as 2124, 2524, 7050, 7175, and 7475 provide excellent toughness at high-yield-strength levels and so are attractive for fracture-critical aerospace and transportation applications.

The 5*xxx* series are also outstanding for high toughness at subzero temperatures, providing both strength and toughness well above room temperature values at temperatures down to –320 °F; even at temperatures as low as –452 °F (near absolute zero), the toughness levels for many of these alloys and tempers are quite high.

For welded structures, 5*xxx* filler alloys are recommended over aluminum alloy 4043 where high toughness is important at any service temperature.

1.2 Introduction

With the continued development of high-strength aluminum alloys and tempers and their use in very critical components in aerospace, automotive, marine, and cryogenic applications, the ability to adequately describe and predict their fracture resistance remains important. These needs range from (a) in alloy development, determining which alloys and tempers of a given group have the greatest fracture resistance, (b) in alloy selection, making decisions on alloy choices for specific applications, and (c) in design, establishing safe design stresses and/or predicting critical crack or discontinuity sizes under specific service conditions.

Most commercial aluminum alloys and tempers are so tough that "brittle" or "low ductility fracture" (i.e., unstable or self-propagating crack growth in elastically stressed material) rarely occurs under any conditions. For these alloys, the merit-rating approach is generally sufficient, and measures of notch toughness or tear resistance providing relative qualitative ratings may be sufficient. However, there are a number of higher-strength aluminum alloys and tempers that are used principally in aerospace applications, where strength must be used to the maximum advantage and the consequences of unexpected low-ductility failure must be considered. For these particular alloys and tempers, more precise evaluations of toughness by methods such as fracture toughness testing are required for quantitative evaluation of fracture behavior under specific service conditions and, subsequently, the design of fracture resistance into the structure.

It is the purpose of this publication to build on an earlier work (Ref 1) to (a) describe various criteria for evaluating the toughness or fracture resistance of aluminum alloys, how they are determined, and their usefulness and limitations; (b) provide a background of representative data from various types of toughness tests for a wide range of aluminum alloys and tempers, and (c) provide some general guidance as to which alloys may be most useful for applications where high toughness is vital.

It is not the intent of this book to describe and provide extensive performance data for other types of fracture mechanisms such as fatigue and corrosion beyond showing the logical interfaces. For comprehensive coverage of these subjects and more in-depth design approaches, readers are referred to the work of Bucci, Nordmark, and Stark (Ref 2) in *Fatigue and Fracture*, Volume 19 of *ASM Handbook*. For readers interested in a broader range and depth of discussion on applications for aluminum alloys, as well as other aspects of the aluminum industry, reference is made to Altenpohl's book *Aluminum: Technology, Applications, and Environment* (Ref 3).

Much of the data provided herein are from the highly respected Alcoa Laboratories research organization of Alcoa, Inc., which has been active for more than 40 years in the fracture-testing field. Included are data obtained using consistent and well-documented methods from many papers published by Alcoa scientists, as well as data from several previously unpublished reports. Also presented are representative data from the Aluminum Association fracture toughness database, ALFRAC, put together under contract from the Metals Properties Council and subsequently made available through a grant from the National Institute of Standards and Technology and the National Materials Property Data Network.

The data included herein are not intended to be exhaustive but to provide a good representation of a wide range of types of toughness indexes for a broad spectrum of aluminum alloys, including both wrought and cast alloys. The data are presented for their value in understanding the fracture behavior of aluminum alloys but are not intended for design.

A word of explanation is needed about the inclusion in the book of data for a number of aluminum alloys and tempers that are no longer considered useful for various reasons and that are now designated as obsolete by the Aluminum Association, Inc. Such alloys are included because they may have been used in fracture-critical structures in years past, and so specialists dealing with maintenance and retrofit for such structures may be looking for data on the old alloys. Their inclusion herein provides a useful source and potentially valuable comparisons with data for alloys currently recommended for comparable applications. All obsolete alloys are identified by appropriate footnotes in the tables in which they appear.

It is also appropriate to note that all the data presented and discussed in this book were generated in accordance with the ASTM Standard Test Methods (Ref 4–11) applicable at the time. While there has been some evolution in those standards over the years, especially in the field of fracture toughness testing, the results presented are believed to have been determined by procedures reasonably, if not exactly, consistent with current standards.

Finally, some explanation is needed about the treatment of units in this book. Because all of these data were generated in an environment using

English/engineering units, and because of the mass of data involved, the entire book is presented in English units. While the normal ASM International and Aluminum Association, Inc. policies (Ref 12) are to present engineering and scientific data in both International Standard (SI) and English/engineering units, an appreciable amount of time and expense would be required for the complete conversion and for the dual presentation of all the tables included herein. In addition, the inevitable compromises surrounding rounding techniques for such conversions with a multitude of complex units have been avoided. Those readers interested in SI conversion are referred to Appendix 2 for some guidance.

Some additional valuable sources on aluminum alloy products, standards, and properties are included for the reader (Ref 12–18).