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Corrosion of metals and alloys — Measurement of the electrochemical critical localized corrosion temperature (E-CLCT) for Ti alloys fabricated via the additive manufacturing method

Corrosion des métaux et alliages — Mesurage de la température critique de la corrosion localisée électrochimique pour les alliages de Ti fabriqués à l'aide d'une méthode de fabrication additive

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Foreword

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This document was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Ti alloys such as Ti-6Al-4V are considered the most promising engineering materials. Due to a unique combination of high strength-to-density ratio and increased mechanical and corrosion resistance, their applications are growing in a wide range of industries, e.g. aerospace, automobile, marine and biomedical fields.

Ti alloys are conventionally produced by wrought or cast processes, which are subtractive manufacturing (SM) methods. The recent emergence of a new additive manufacturing (AM) method known as “3D printing” has gained worldwide attention as a way to cut costs and improve efficiency for small quantity, batch productions.

Additively manufactured Ti alloys are extensively investigated for their usage in aerospace and medical applications. When AM is compared with conventional manufacturing, the buy-to-fly ratio is known to be around 15:1 (conventional). In terms of mechanical viewpoints, both the strength and ductility of Ti alloys such as Ti-6Al-4V fabricated via AM are comparable to or superior to those developed via conventional manufacturing methods, because of their unique microstructure based on laser or electron beam technologies. However, the characteristics of additively manufactured alloys are highly dependent upon the geometric and processing conditions (and there are over 130 variables) such as layer formation (imbedded or sprayed), size and quality of powder or wire, dimension, input energy, layer orientation and surface conditions, and tolerance in the CAD process, which converts the data into additive layers for building parts. The differences in layer orientation and the porosity generated by crossing hatches during the layer-by-layer fabrication process can result in differences in both mechanical and electrochemical properties in AM materials. Heat treatment controls the porosity or the microstructure derived from rapid melting and quenching; however, it cannot eliminate interlayers, which contribute to the differences in the mechanism of localized corrosion in AM materials. The resistance to corrosion of Ti alloys produced via AM is similar to that of conventionally manufactured Ti alloys. The mechanisms of corrosion also differ. Therefore, since the conventional testing methods have shown limited ability for evaluation of those properties, the new test method measuring electrochemical critical localized corrosion temperature (E-CLCT) has been developed to evaluate pitting and crevice corrosion in alloys generated via AM. E-CLCT is defined as the lowest temperature on the surface of the AM specimen on which localized corrosion to both pitting and crevice corrosion is initiated under specified test conditions.

This document specifies a procedure for evaluation of the resistance to localized corrosion on the AM alloys by measuring their E-CLCT, providing an efficient method for a qualitative evaluation or comparison of corrosion properties between AM materials or their heats with altered process variables. This test method demonstrates the quality of heat treatment, bonding integrities between layers, and effective control of variables for AM materials, providing a qualitative tool for long-term application. Furthermore, this document can extend its use from AM Ti-alloys to other AM alloys, such as Ni alloys by modifying the concentration of test solutions or the applied potentials. This document also provides important clues to evaluate other types of localized corrosion such as corrosion cracking and erosion-corrosion. Related documents can be developed and followed up based on the results of this test.

Corrosion of metals and alloys — Measurement of the electrochemical critical localized corrosion temperature (E-CLCT) for Ti alloys fabricated via the additive manufacturing method

1 Scope

This document specifies procedures for testing the resistance to localized corrosion of Ti alloys fabricated via additive manufacturing (AM) method. This document regulates the electrochemical critical localized corrosion temperature (E-CLCT) of the AM Ti materials for a comparative evaluation of resistance to localized corrosion.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
electrochemical critical localized corrosion temperature
E-CLCT
lowest temperature on the surface of the AM Ti alloy specimen at which stable localized corrosion, including both pitting and crevice corrosion, occurs under specified test conditions

3.2
temperature ramp rate
rate at which the surface temperature of the specimen increases during the test

4 Main contents and limitations of existing standards

4.1 Application coverage of ISO 17864

The test method in ISO 17864 determines the critical pitting temperature (CPT) using a potentiostatic technique with a temperature scan. The current is monitored during the temperature scan, and CPT is defined as the temperature at which the current increases rapidly, which for practical reasons is defined as the temperature at which the current density exceeds 100 μA/cm^2 for 60 s. Pitting on the specimen is confirmed visually after the test.

4.2 Limitations of ISO 17864

ISO 17864 is useful to measure the resistance of pitting corrosion for stainless steel and related alloys. This method applies to wrought or cast products. However, this method cannot be used for Ti alloys fabricated via AM, which are superior to stainless steels in terms of resistance to pitting, and fabricated via SM. Therefore, it requires much higher potential and more aggressive corrosion environment.

4.3 Scope of ISO 18089

The test method in ISO 18089 determines the critical crevice temperature (CCT) via a potentiostatic technique using a temperature scan. The current is monitored during the temperature scan. CCT is defined as the temperature of a specimen beneath the crevice former at which the current increases rapidly. Crevice corrosion on the specimen is confirmed visually after the test.

4.4 Limitations of ISO 18089

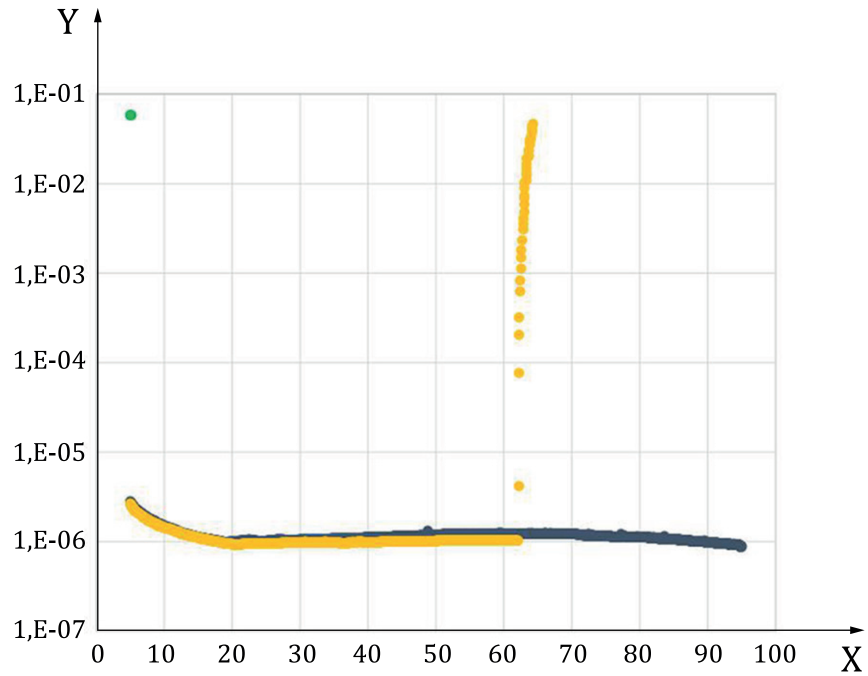
This document is useful for the measurement of resistance to crevice corrosion of stainless steel and related alloys and this method applies to wrought or cast products. However, this method cannot be used for Ti alloys fabricated by AM where crevice corrosion does not occur on the specimen surface beneath the crevice former.

5 Principle

This test method generally describes laboratory tests for the measurement the E-CLCT of AM Ti alloys, based on ISO 17864 and ISO 18098. Therefore, test temperature sweep rate, basic apparatus and test procedures are similar to those standards, except for the concentrated corrosive aqueous test solution, much higher applied potentials and the Ti-alloy specimens fabricated by AM. The resistance to localized corrosion of AM Ti alloys shall be evaluated in terms of initiation of pitting or crevice corrosion or both, because of much higher pore density and varying orientation compared with those of conventional wrought alloys. In ISO 18098, CCT is determined by using a crevice former, which is the component of the crevice corrosion test tool assembly, and which allows crevice corrosion to be induced in a contacted test specimen by applying certain torques. However, in the case of AM Ti alloys, pits or crevices are induced from the pores or the edges of the specimen rather than the locations under the crevice former. Therefore, the measurement of E-CLCT does not require the crevice former, i.e. the component of the crevice corrosion test tool assembly. The flushed-port cell for CPT test is not adequate, in which the specimen is separated from the cell port and is mounted outside the cell. The whole specimen shall be immersed in the solution inside the cell, ensuring exposure of specimen parts to solution. Samples exposed to the concentrated sodium chloride (a mass fraction of 25 %) solution, are tested with a potentiostatic technique using a temperature scan. The anodic applied potential is held constant during the whole temperature scan. The current is monitored during the temperature scan. The E-CLCT shall be measured up to the temperature where the current increases rapidly as shown in Figure 1. Figure 2 shows two different shapes of crevice corrosion on Ti-6Al-4V alloys obtained via SM and AM. The different initiation sites are noted in localized corrosion between SM and AM Ti-6Al-4V alloys.

NOTE 1 Some CPT values can be found in Reference [4].

NOTE 2 Some E-CLCT values can be found in Reference [5].



Key

X temperature (in °C)

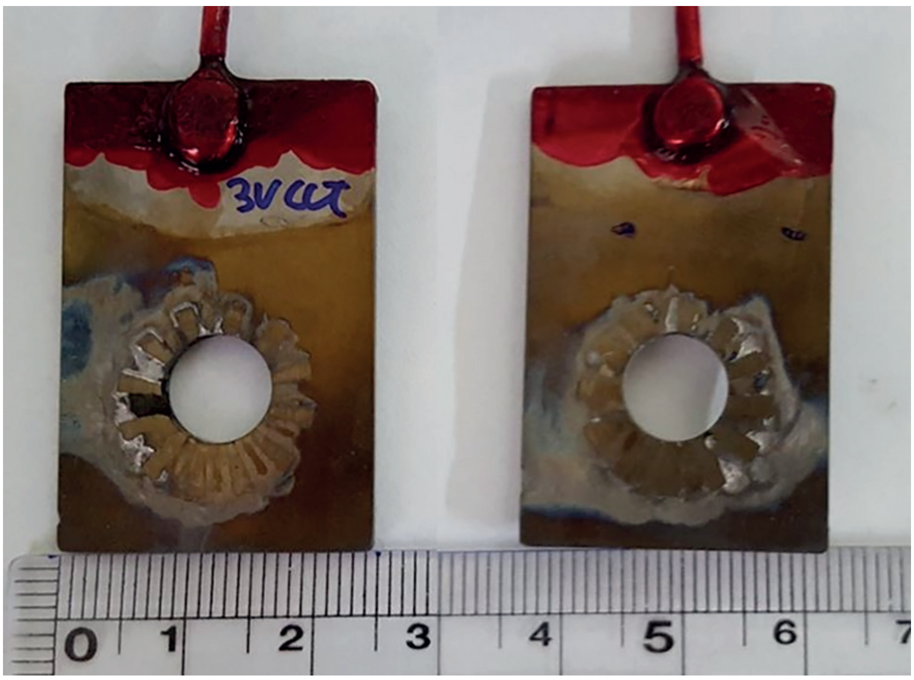
Y current density (in A/cm²)

● AM Cp-Ti

● AM Ti-6AI-4V

● AM Ni7 18

Figure 1 — Determination of E-CLCT values of Ti-6Al-4V, CP-Ti, and Ni718 for the side edge parallel to the AM direction produced by additive manufacturing, according to applied potentials of 2,8 V with respect to saturated calomel electrode in the concentrated sodium chloride (mass fraction of 25 %) solution



a) Subtractive-manufactured Ti-6Al-4V alloys

