Influence of manufacturing process on Cavitation Erosion in CoCrWMoCFeNiSiMn (Stellite 1) alloysDissertation title

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Abstract

The lifespan and reliability of components subjected to severe cavitation and corrosion erosion depend critically on material properties and failure mechanisms. The microstructure, and hence performance, of wear-resistant alloys used in such aggressive conditions is not dictated by chemical composition alone but is critically shaped by manufacturing process. Cobalt-based Stellite alloys are a primary choice for these applications, deriving their exceptional wear resistance from hard carbide phases embedded within a tough cobalt-alloy matrix. Traditionally, these alloys are produced by casting, which often produces a coarse and brittle carbide network. In contrast, powder metallurgy routes, such as Hot Isostatic Pressing (HIP), yield a significantly more refined and homogeneous microstructure, offering a pathway to superior durability. However it remains a critical question whether the microstructural refinement achieved through HIPing enhances toughness and fatigue resistance in high carbon alloys like Stellite 1, particularly in the context of cavitation erosion. Here we show, by directly comparing a cast and a HIPed cobalt alloy (Co-30Cr-12W-2.5C by wt%), that the HIPing route produces a material with superior cavitation erosion and order of magnitude greater corrosion resistance to its cast counterpart.

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1. Introduction

Cavitation erosion, the mechanical degradation of surfaces due to collapse of bubbles and the resulting high-frequency high-pressure shock waves, is a common failure mechanism that limits the durability and service life of hydraulic components operating in aggressive service environment [1, 2].

Stellites, a family of cobalt-based superallys, are widely used in industry to resist cavitation, in addition to their strength, wear resistance, and corrosion/oxidation resistance at high temperatures. The main alloying elements of cobalt (Co), chromium (Cr, 25-33 wt.%), tungsten (W) or molybdenum (Mo) (up to 18 wt.%), and carbon (C, 0.1-3.3 wt.%) [3, 4], form a composite-like microstrucuture consisting of a ductile cobalt-rich solid solution, which absorbs energy through a sluggish FCC to HCP phase transformation, with embedded hard carbide phases [5–8]. The proportion and type of carbides depend on carbon content and the relative amounts of chromium (of carbide type M_7C_3, $M_{23}C_6$) and tungsten and molybdenum (of carbide type M_6C, $M_{12}C$), with the solid solution strengthened by incorporating the elements not consumed in

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carbides. The size and distribution of the carbides, and the resulting microstructure, is heavily dependent on its manufacturing process, especially the rate of solidification. For instance, the slow freezing rates inherent to traditional casting lead to a microstructure of large, dendritic carbides characterized by elemental segregation. Conversely, powder metallurgy creates a highly homogeneous microstructure with small, spherical carbides by largely retaining the properties of the initial powder [9, 10].

Wong-Kian et al [10] found that HIPed Stellite 1, 6, and 21 had superior erosion-corrosion characteristics to welded coatings when subjected to nitric acid in slurry pot, as well as found that increasing contents of chromium, carbonm and tungsten resulted in better performance.

Ashworth et al investigated the effect of found that high carbon Stellite alloys benefitted from higher hipping temperatures (1200 C) while low carbon Stellite alloys reached optimum properties at a HIPing temperature of 1120 C [2].

Yu et al [9] found that HIPed stellite 6 had lower fatigue performance to HIPed stellite 20.

frenkMicrostructuralEffectsSliding1994 has good notes on effects of manufacturing

As well as the corrosion behaviour being of interest, Malayoglu and Neville [16] conducted a comparative study on the erosion-corrosion performance of both HIPed and investment cast Stellite 6ő in 3.5% NaCl solution as a function of temperature and the level of erosive particle loading. They found that in all cases, the HIPed Stellite 6ő exhibited the higher erosioncorrosion resistance, which they attributed to the fact that the carbides are not interconnected in the HIPed material whereas eutectic and dendritic carbides in the cast structure form a network of interconnected material. Furthermore, the mean free path between carbides is much smaller in the HIPed material and as such the material responded homogenously to 4 erosion-corrosion. Another study comparing the erosion-corrosion behaviour of a range of HIPed and weld-deposited Stellite alloys in a nitric acid environment demonstrated that the HIPed alloys generally exhibited a lower mass loss which was again attributed to the finer microstructure [17]. A similar conclusion was also reached by Neville and Malayoglu [18] who attributed the superior corrosion resistance of HIPed Stellite 6 to its microstructure with equiaxed carbides and an absence of areas of chromium-depleted matrix material, due to reduced segregation.

krellComprehensiveInvestigationMicrostructureproperty2020

Although cobalt-based alloys are extensively studied <?>, a knowledge gap exists in understanding how different processing routes affect their cavitation erosion resistance. To address this, our work provides a direct comparison of the structure-property relationships in alloys produced by casting and powder-consolidated Hot Isostatic Pressing (HIP). We characterized the alloys through microstructural analysis (SEM) and evaluated their relative tribo-mechanical performance based on hardness, impact toughness, resistance to abrasive and sliding wear, and contact fatigue.

2. Discussion

The as-cast Stellite 1 alloy had a hypereutectic microstructure, with the Cr-rich (dark) carbides having a composition of $\$(\mathrm{Cr}_{0.75}\mathrm{Co}_{0.20}\mathrm{W}_{0.05})_{7C3})\}$ and identified as M_7C_3, and W-rich (dark) regions having a composition of $(Co_{0.6}W_{0.6})_{12}C$ and identified as $M_{12}C$. Cr-rich carbides

2.1. Carbide volume fraction

As hard phases (carbides and intermetallics) contribute to hardness and wear resistance, it is beneficial to estimate the volume fraction of different phases, through thresholding BSE images

In the present work, BSE images were taken on the polished samples, and thresholded using histogram analysis, with ten readings taken and averages to calculate the volume fraction of hardness phases.

Stellite 1 includes two kinds of carbides, chromium rich carbides and tungsten-rich carbides.

ratiaComparisonSlidingWear2019 The total volume fraction of carbides

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Appendix A. Essential appendices

Essential appendices; ie, detail without which the main paper is difficult to understand should be included here.

Appendix B. List of further material in the Work Progress Report

All working material and non-essential appendices must be submitted separately as the 'Work Progress Report'. There is no need to refer to that material. However, if you feel that certain sections or files in that report would be useful to the reader, you can list here that material and how to find it in the Work Progress Report submission.