How To Make A Thesis Following The Guideline With More Text To Have Two Lines

by

A Good Name

Submitted for the degree of

Doctor of Philosophy

Some weird institute no one ever heard about
School of Latex and Writing
Heriot-Watt University

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Abstract

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Acknowledgements

I wanna thanks all coffee and tea manufacturers and sellers that made the completion of this work possible.

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Glossary

GCD	Greatest Common Divisor.
LCM	Least Common Multiple.

List of Publications

1 F. Awesome, *Frank*, 2005.

2 F. Awesome, *Frank, but lowercase*, 2006.

Part I

Chapters

Chapter 1

Introduction

Stellites are a cobalt-base superalloy used in aggresive service environments due to retention of strength, wear resistance, and oxidation resistance at high temperature [1].

Originating in 1907 with Elwood Haynes's development of alloys like Stellite 6, Stellites quickly found use in orthopedic implants, machine tools, and nuclear components, and new variations on the original CoCrWC and CoCrMoC alloys are spreading to new sectors like oil & gas and chemical processing [1], [2].

Stellites generally contain 25-33 wt Cr, 4-18 W/Mo, and 0.1-3.3 wt C, with a microstructure consisting of a CoCr(W,Mo) matrix with solid solution strengthening, with hard carbide phases, usually with Cr (e.g., M_7C_3, $M_{23}C_6$), and W/Mo (e.g. MC, M_6C); the proportion and type of carbides depend on carbon content and the relative amounts of carbon with carbide formers (Cr, W, Mo), as well as processing routes. In addition to the solid solution toughness and carbide hardness, the stress-induced FCC tp HCP phase transformation of the Co-based solid solution further increases wear resistance through work hardening.

The remarkable ability of Stellite alloys to withstand these specific challenges stems from key metallurgical features. Their corrosion resistance is primarily attributed to a high chromium content, typically 20-30 wt.%, which promotes the formation of a highly stable, tenacious, and self-healing chromium-rich passive oxide film on the material's surface; this film acts as a barrier isolating the underlying alloy from the corrosive environment. Alloying elements such as molybdenum and tungsten can further enhance this passivity, particularly improving resistance to localized corrosion phenomena like pitting and crevice corrosion in aggressive media. Concurrently, their outstanding cavitation resistance is largely derived from the unique behavior of the cobalt-rich matrix, which can undergo a stress-induced crystallographic transformation from a face-centered cubic (fcc) to a hexagonal close-packed (hcp) structure. This transformation, often facilitated by mechanical twinning, effectively absorbs the intense, localized impact energy from collapsing cavitation bubbles and leads to significant work hardening, thereby impeding material detachment and erosion.

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1.1 Table: Show the table of stellite compositions

1.2 Table: Show the table of stellite compositions

LaTeX

Table 1.1: Stellite Compositions

	Base		Refractory		Carbon	Others										
Alloy	**Co**	**Cr**	**W**	**Mo**	**C**	**Fe**	**Ni**	**Si**	**P**	**S**	**B**	**Ln**	**Mn**	**Ref**	**Process Type**	**Observation**
Stellite 1	41.1	30.5	12.5		2.4	<5	<3.5	<2			<1		<2	[3]		
	47.7	30	13	0.5	2.5	3	1.5	1.3					0.5	[3]		
	48.6	33	12.5	0	2.5	1	1	1.3					0.1	[4]		
	46.84	31.7	12.7	0.29	2.47	2.3	2.38	1.06					0.26	[5]	HIPed	ICP-OES
Stellite 3	50.5	33	14		2.5									[6]		
	49.24	29.57	12.07	0.67	2.52	2.32	1.07	1.79					0.75	[7]	HIPed	ICP-OES and combustion infrared det
Stellite 4	45.43	30	14	1	0.57	3	3	2					1	[3]		
	51.5	30	14		1	1	2	0.5						[8]		
	51.9	33	14		1.1									[6]		
	49.41	31	14	0.12	0.67	2.16	1.82	1.04					0.26	[5]	HIPed	ICP-OES
	50.2	29.8	14.4	0	0.7	1.9	1.9	0.8					0.3	[9]	HIPed	
Stellite 6	51.5	28.5	4.5	1.5	1	5	3	2			1		2	[3]		
	63.81	27.08	5.01		0.96	0.73	0.87	1.47					0.07	[7]	HIPed	ICP-OES and combustion infrared det
	60.3	29	4.5		1.2	2	2	1						[8]		
	61.7	27.5	4.5	0.5	1.15	1.5	1.5	1.15					0.5	[6]		
	58.46	29.5	4.6	0.22	1.09	2.09	2.45	1.32					0.27	[5]	HIPed	ICP-OES
	58.04	30.59	4.72		1.24	2.03	1.87	0.80	0.01	0.01				[10]	PTAW	OES
	55.95	27.85	3.29		0.87	6.24	3.63	1.23	0.01	0.01			0.45	[10]	GTAW	OES
	52.40	30.37	3.57		0.96	6.46	3.93	1.70	0.01	0.01			0.3	[10]	SMAW	OES
	60.3		31.10	4.70	0.30	1.10	1.70	1.50	1.30		0.00		0.3	[11]	LP-DED	ICP-AES & GDMS
	60.6	27.7	5	0	1.2	1.9	2	1.3					0.3	[9]	HIPed	
Stellite 7	64	25.9	4.9	0	0.5	1.5	1.1	1.1					1	[9]	HIPed	
Stellite 12	53.6	30	8.3		1.4	3	1.5	0.7					1.5	[3]		
	55.22	29.65	8.15	0.2	1.49	2.07	2.04	0.91					0.27	[5]	HIPed	ICP-OES
Stellite 19	50.94	31.42	10.08	0.79	2.36	1.82	2	0.4			0.09		0.1	[12]		
Stellite 20	41.05	33	17.5		2.45	2.5	2.5						1	[3]		
	43.19	31.85	16.3	0.27	2.35	2.5	2.28	1					0.26	[5]	HIPed	ICP-OES
Stellite 21	59.493	27		5.5	0.25	3	2.75	1			0.007		1	[3]		
	60.6	26.9	0	5.7	0.2	1.3	2.7	1.9					0.7	[9]	HIPed	
Stellite 22	54	27		11	0.25	3	2.75	1					1	[3]		
Stellite 23	65.5	24	5		0.4	1	2	0.6					0.3	[3]		
Stellite 25	49.4	20	15		0.1	3	10	1					1.5	[3]		
Stellite 27	35	25		5.5	0.4	1	32	0.6					0.3	[3]		
Stellite 30	50.5	26		6	0.45	1	15	0.6					0.6	[3]		

1.3 Paragraph 4: Synergistic Challenges in Applications Prone to Corrosion and Cavitation IGNORE

1.4 Paragraph 5: Research and Development for Enhanced Corrosion and Cavitation Performance IGNORE

1.5 Paragraph 6: Influence of HIPing IGNORE

Compared with the case alloys, the HIPed alloys had relatively finer, rounded, and distributed carbides.

1.6 General Background

%% have a mini table of content at the start of the chapter {

Contents

}

%cite:@Franc2004265, @Romo201216, @Kumar2024, @Kim200685, @Gao2024, @20221xix, @Usta2023, @Cheng2023, @Zheng2022

Cavitation erosion presents a significant challenge in materials degradation in various industrial sectors, including hydroelectric power, marine propulsion, and nuclear systems, stemming from a complex interaction between fluid dynamics and material response [13], [14]. Hydrodynamically, the phenomenon initiates with the formation and subsequent violent collapse of vapor bubbles within a liquid, triggered by local pressures dropping to the saturated vapor pressure. These implosions generate intense, localized shockwaves and high-speed microjets that repeatedly impact adjacent solid surfaces [15]. From a materials perspective, these impacts induce high stresses (100-1000 MPa) and high strain rates, surpassing material thresholds and leading to damage accumulation via plastic deformation, work hardening, fatigue crack initiation and propagation, and eventual material detachment. Mitigating this requires materials capable of effectively absorbing or resisting this dynamic loading, often under demanding conditions that may also include corrosion.

Stellite alloys, cobalt-chromium formulations that contain carbon, tungsten and/or molybdenum, represent a critical class of materials renowned for their wear resistance in such harsh environments [16]. Their performance stems from a composite-like microstructure combining a strong cobalt-rich matrix, strengthened by solid solutions of Cr and W/Mo, with hard carbide precipitates (e.g., M7C3, M23C6) that impede wear and crack propagation [17], [18].

% Martensitic transformation Crucially, the cobalt matrix often possesses a low stacking fault energy, facilitating a strain-induced martensitic transformation from a metastable face-centered cubic γ phase to a hexagonal close-packed ε phase under the intense loading of cavitation. This transformation is a primary mechanism for dissipating impact energy and enhancing work hardening, contributing significantly to Stellite's characteristic cavitation resistance [19], [20].

HIPing is a thermo-mechanical material processing technique which involves the simultaneous application of pressure (up to 200 MPa) and temperature (2000 C), which results in casting densification, porosity closure, and metallurgical bonding. [21]

While commonly applied via casting or weld overlays, processing routes like Hot Isostatic Pressing (HIP) offer potential advantages such as microstructure refinement [22] finer microstructures and enhanced fatigue resistance [21], [23].

HIPing of surface coatings results in microstructure refinement, which can yield improved fatigue and fracture resistance.

HIPing leads to carbide refinement, which can yield improved impact toughness [24], and reduce carbide brittleness [21].

Furthermore, HIP facilitates the consolidation of novel 'blended' alloys created from mixed elemental or pre-alloyed powders, providing a pathway to potentially tailor compositions or microstructures for optimized performance. However, despite the prevalence of Stellite alloys and the known influence of processing on microstructure and properties, the specific cavitation erosion behavior of HIP-consolidated Stellites, particularly these blended formulations, remains underexplored in academic literature. Given that erosion mechanisms in Stellites often involve interactions at the carbide-matrix interface [25], understanding how HIP processing and compositional blending affect these interfaces and the matrix's transformative capacity under cavitation, especially when potentially coupled with corrosion, constitutes a critical knowledge gap addressed by this research.

% Need to describe Stellite 1

1.7 Stellite 1

Stellite 1 is a high-carbon and high-tungsten alloy, making it suitable for demanding applications that require hardness & toughness to combat sliding & abrasive wear [18]

1.8 Stellites

1.9 Objectives and Scope of the Research Work

1.10 Thesis Outline

1.11 Literature Survey

1.12 Cavitation Tests

Chapter 2

Analytical Investigations

Chapter 3

Experimental Investigations

3.1 Materials and Microstructure

The HIPed alloy was produced via canning the gas-atomized powders at 1200C and 100 MPa pressure for 4h, while the cast alloys were produced via sand casting. % Sieve analysis and description of powders

% Refer to Table of chemical compositions of both cast and HIPed alloys.

The microstructure of the alloys were observed via SEM in BSE mode, and the chemical compositions of the identified phases developed in the alloys were determined via EDS as well as with XRD under Cu K_α radiation.

Image analysis was also conducted to ascertain the volume fractions of individual phases.

The Vickers microhardness was measured using a Wilson hardness tester under loads of BLAH. Thirty measurements under each load were conducted on each sample.

Chapter 4

Discussion

4.1 Experimental Test Procedure

4.1.1 Hardness Tests

4.1.2 Cavitation

4.2 Relationships between cavitation erosion resistance and mechanical properties

4.3 Influence of vibratory amplitude

% Insert the whole spiel by that French dude about displacement and pressure (and then ruin it) The pressure of the solution depends on the amplitude of the vibratory tip attached to the ultrasonic device. Under simple assumptions, kinetic energy of cavitation is proportional to the square of the amplitude and maximum hammer pressure is proportional to A.

$$x = Asin(2\pi ft) \tag{4.1}$$

$$v = \frac{dx}{dt} = 2\pi fAsin(2\pi ft) \tag{4.2}$$

$$v_{max} = 2\pi fA \tag{4.3}$$

$$v_{mean} = \frac{1}{\pi}\int_0^{\pi} Asin(2\pi ft) = 4fA \tag{4.4}$$

$$\tag{4.5}$$

However, several researchers have found that erosion rates are not proportional to the second power of amplitude, but instead a smaller number. Thiruvengadum [26] and Hobbs find that erosion rates are proportional to the 1.8 and 1.5 power of peak-to-peak amplitude. Tomlinson et al find that erosion rate is linearly proportional to peak-to-peak amplitude in copper [3]. Maximum erosion rate is approximately proportional to the 1.5 power of p-p amplitude [4]. The propagation of ultrasonic waves may result in thermal energy absorption or into chemical energy, resulting in reduced power. For the purposes of converting data from studies that do not use an amplitude of 50um, a exponent factor of 1.5 has been applied.