

بسم الله الرحمن الرحيم



HOSSAM MAGHRABY



شبكة المعلومات الجامعية التوثيق الالكتروني والميكرو فيلم



HOSSAM MAGHRABY

جامعة عين شمس

التوثيق الإلكتروني والميكروفيلم

قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها
على هذه الأقراص المدمجة قد أعدت دون أية تغيرات



يجب أن

تحفظ هذه الأقراص المدمجة بعيدا عن الغبار



HOSSAM MAGHRABY



بعض الوثائق الأصلية تالفة



HOSSAM MAGHRABY



بالرسالة صفحات

لم ترد بالأصل



HOSSAM MAGHRABY

B149/11

SUEZ CANAL UNIVERSITY
FACULTY OF ENGINEERING AND TECHNOLOGY

MECHANICAL BEHAVIOUR OF POWDER METALLURGICAL MATERIALS

A THESIS

*Submitted to the Faculty of Engineering and Technology
Suez Canal University for the Ph.D. Degree in
Mechanical Engineering*

By

AHMED ELSAYED ALY NASSEF

*M.Sc., B.Sc. in Mechanical Engineering,
Faculty of Engineering and Technology,
Suez Canal University, Port-Said, EGYPT.*

Supervised by

■ **Prof.Dr.Eng. M.A.El-Salamoni**

Cairo University,
Faculty of Eng.
Cairo, Egypt.

Prof.Dr.Eng. E.El-Magd

Aachen University,

Lehr-u. Forschungsgebiet Werkstoffkunde

RWTH. Aachen, Germany.

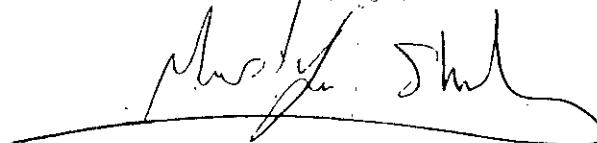


■ **Prof.Dr.Eng. M.H.El-Boragy**

Suez Canal University,
Faculty of Eng. and Tech.,
Port-Said, Egypt.

Prof.Dr.Eng. M.A.Shaker

Suez Canal University,
Faculty of Eng. and Tech.,
Port-Said, Egypt.



PORT-SAID

1994

SUEZ CANAL UNIVERSITY
FACULTY OF ENGINEERING AND TECHNOLOGY

**MECHANICAL BEHAVIOUR OF POWDER
METALLURGICAL MATERIALS**

A THESIS

*Submitted to the Faculty of Engineering and Technology
Suez Canal University for the Ph.D. Degree in
Mechanical Engineering*

By

AHMED ELSAYED ALY NASSEF

*M.Sc., B.Sc. in Mechanical Engineering,
Faculty of Engineering and Technology,
Suez Canal University, Port-Said, EGYPT.*

Supervised by

■ **Prof.Dr.Eng. M.A.El-Salamoni**

Cairo University,
Faculty of Eng.
Cairo, Egypt.

Prof.Dr.Eng. E.El-Magd

Aachen University,

Lehr-u. Forschungsgebiet Werkstoffkunde

RWTH, Aachen, Germany.



■ **Prof.Dr.Eng. M.H.El-Boragy**

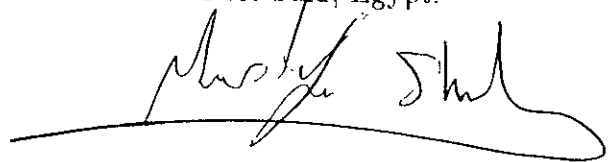
Suez Canal University,
Faculty of Eng. and Tech.,
Port-Said, Egypt.

Prof.Dr.Eng. M.A.Shaker

Suez Canal University,

Faculty of Eng. and Tech.,

Port-Said, Egypt.



PORT-SAID

1994

Approved by

1- Prof.Dr.Eng. Ahmed Salem Elsabagh

Production Engineering Department,

Faculty of Engineering, Ain Shams University,

Cairo, Egypt.

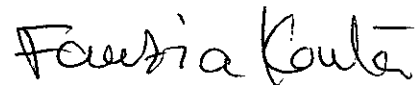


2- Prof.Dr.Eng. Fawzia H. Hamze Kouta

Production Engineering Department,

Faculty of Engineering, Cairo University,

Cairo, Egypt.

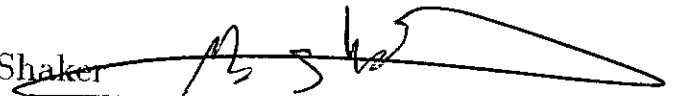


3- Prof.Dr.Eng. Mostafa Ahmed Shaker

Production Engineering Department,

Faculty of Engineering and Technology,

Suez Canal University, Port-Said, Egypt.



Contents

1	Introduction	6
1.1	The objective of the research work:	8
2	Literature Review	9
2.1	316L - Powder Alloy	10
2.2	Super Powder Alloy Udimet-700	11
2.3	Stellite Powder Alloy No. 6	13
2.4	Powder Metallurgical Processes	16
2.4.1	Hot Isostatic Pressing (HIP)	16
2.4.1.1	Densification During HIP	18
2.4.1.2	Modelling Densification During HIP	19
2.4.2	Metal Injection Molding (MIM)	23
2.4.2.1	MIM Equipment	23
2.4.2.2	Steps of MIM Process	23
2.4.3	Wet Powder Pouring (WPP)	29
2.5	Mechanical Tests	31
2.5.1	Hot Hardness Test	31
2.5.2	Hot Tensile Test	31
2.5.3	Creep Behaviour	32
2.5.4	Fatigue Test	37
3	Experimental Work	41
3.1	Production of P/M Materials	42

3.1.1	Fe-base Alloy (316L Stainless Steel)	42
3.1.1.1	MIM process for 316L alloy	42
3.1.1.2	Hot Isostatic Pressing Process	51
3.1.1.3	Heat Treatment for 316L	56
3.1.2	Ni-base Powder Superalloy (Udimet 700)	57
3.1.2.1	Wet Powder Pouring Process	57
3.1.3	Co-base Alloy (Stellite Alloy No. 6)	59
3.1.3.1	Hot Isostatic Pressing Process	61
3.1.3.2	Wet Powder Pouring Process	64
3.1.3.3	Heat Treatment of Stellite Alloy No. 6	65
3.2	Mechanical Test Procedure	67
3.2.1	Hot Hardness Test	67
3.2.2	Tensile Test	67
3.2.3	Creep Test Procedure	70
3.2.4	Rotating-bending Fatigue Machine	70
3.2.5	Metallographic Investigation	77
4	Results and Discussions	78
4.1	316L Alloy	78
4.1.1	Heat Treatment	80
4.1.2	Hot Tensile Test	82
4.1.3	Creep Data Presentations	89
4.1.4	Metallographic Investigation	107
4.2	Superalloy U-700	112
4.2.1	Hot Tensile Test	112
4.2.2	Creep Test Properties	112
4.2.3	Metallographic Investigation	128
4.3	Stellite Alloy No.6	130
4.3.1	Microhardness and Microstructure	130
4.3.2	Heat Treatment	130
4.3.3	Hot Hardness Test	135

4.3.4	Tensile Test	143
4.3.5	Fatigue Test	146
4.3.6	Metallographic Investigation	152
4.3.7	Correlation Between the Mechanical Test Results of Stellite-6 . . .	156
5	CONCLUSIONS AND FUTURE RECOMMENDATIONS	
5.1	Conclusions	160
5.2	Future Recommendation	162
6	References	163
	References	
6.1	Arabic Summury	172

ACKNOWLEDGEMENT

The author wishes to express his sincere gratitude to deceased Prof.Dr.Eng. M.El-Salamoni, Cairo University, for his help, supervision, kindness and linking the academic channel system between Egypt and Germany. His help and support aided the initiation of this work. Thanks are also given to deceased Prof.Dr.Eng. M.H.El-Boragy, Suez Canal University, Faculty of Engineering, for his supervision.

Deepest gratitude and all thanks are presented to Prof.Dr.Eng.E.A.El-Magd, not only for suggesting the subject of the research, but also for his valuable help, advice and supervision at the Lehr-und Forschungsgebiet Werkstoffkunde, Faculty of Mechanical Engineering, Technical University of Aachen, Germany. In addition, the author is much indebted to Prof.Dr.Eng. M.A.Shaker, Suez Canal University, Faculty of Engineering, not only for revising the thesis, but also for his useful discussion and advises. The author also acknowledges the help and support provided by Lehr-und Forschungsgebiet Werkstoffkunde in Aachen, Germany. Thanks are also due to Prof.Dr.rer.nat.R.Hecker, Dr.Stover and Dr.Buchkremer for their generous support and for providing of the powder metal and other facility during my work in their Institute.

This work has been supported by the Ministry of High Education, in Egypt.

ABSTRACT

Different powder metallurgy (P/M) production techniques for some widely used metal compounds, primarily to take advantage of possibility to produce technical parts with near net shape technique instead of the usual way of casting usually followed by expensive machining to achieve the desired geometry of the work piece.

The selection of investigated P/M alloys 316L, Udimet-700 and Stellite alloy No. 6, were chosen because of wide spectrum of their technical application and because of the fact - with some exceptions - that they are up to now, normally not produce parts by the powder metallurgical route.

The manufacturing of the parts are performed by : 1) Metal Injection Moulding (MIM)-debinding - sintering. In this method (MIM), the powder is first binded into a solid "green body" then extruded similarly to the polymers. 2) Wet Powder Pouring (WPP) - debinding and sintering in one process . In both cases ultimate densification to solid density is performed by subsequent "HIPing" of the sintered bodies. The new methodology (WPP) of mixing the powder with the binder and liquid suspension have been poured on a rubber mold without applying pressure. The process has been carried out at room temperature. The new technique has been developed as a fast and economic nearest net shape forming. 3) Hot Isostatic Pressing (HIP), only, HIPing of the powder alloy poured into an adequate formed capsule, which is then evacuated before sealing.

Widely optimised "programs" for debinding and sintering have been performed to achieve 95 % of the solid density of the end products. The subsequent containerless "HIPing" of part alloy have attributed due to the 95 % of the solid density.

The samples of the different alloys are produced in different ways:

1) In the case of 316L steel samples are prepared via MIM-sintering and HIPing and compared with samples prepared by HIP and by conventional metal forming processes as hot rolling. Three different time functions for heating during the HIP process and six different heat treatments were applied to optimize the properties. High temperature creep tests were carried out on the P/M material with the different production and treatment condition. In addition a commercial hot-rolled material was heat treated and tested

under the same creep conditions. The comparison showed that the powder metallurgically produced material has at least the same creep resistance as the rolled one.

2) Udimet-700 samples are produced via the route WPP-sintering and HIPing plus different production heat treatments. As superalloy, the production of this material is much more difficult than the first one. By using this method, the material shows clearly higher creep resistance properties as those of the rolled alloy and those determined in previous investigation using other powder metallurgical methods (HIP).

3) Stellite alloy No. 6 samples were prepared again just via HIP and these samples were compared to those produced via WPP-Sintering-HIPing and those commercially available. Rotating bending fatigue tests were carried out and fatigue limit statistically evaluated according to the Weibull analysis. The material was studied at different stress amplitude levels in order to determine the Weibull curves for 10, 50 and 90 % survival probability. In comparative tests, the corresponding curves were determined for the commercially available wrought material. The comparison showed that the P/M processing materials have higher endurance limit than the commercial one in its as delivered condition. Similar results were obtained for hardness at low and high temperatures.

The materials producing by the WPP-Sintering and HIPing, usually have lower strength and toughness values than capsule-HIPed ones, different cycles of heat treatments were tried out in order to improve the microstructure. Metallurgical study and elevated temperature tension tests showed that strength and ductility can be seriously increased after using an adequate heat treatment.

Nomenclature

Aa	are constant depending on the test creep conditions
B	creep stress constant
$b > 0$	Weibull shape (or 'slope') parameter
bcc	body-centred-cubic
C	Larson Miller constant ($C=20$)
$Conv.$	conventional
d	particle size
$d_{(RT)}$	diagonal at room temperature
d_T	diagonal at test temperature
$F(N)$	the cumulative function for the fracture of population failed
fcc	face-centred-cubic
HIP	Hot Isostatic Pressing
$H.T.$	Heat Treatment
HV	Vickers Hardness at room temperature
K_1, K_2	creep constants
MIM	Metal Injection Molding
m	stress exponent for rupture results
N	specimen fatigue life
$N_0 \geq 0$	minimum fatigue life parameter
N_a	characteristic fatigue life parameter
n	creep stress exponent
P	Pressure
P/M	Powder Metallurgy
Q_c	activation energy
R	universal gas constant (8.314 KJ/(mol. K))
RT	Room Temperature
r	rate approach to steady state creep
T	Temperature