



TINGASSIFIED	MASTER COPY	-	FOR REP	RODUCTION	PURPOSES
AD-A184 944	REPORT DOCUM	AENTATION	PAGE	IC FILE	COP
	TIC	1b. RESTRICTIVE	MARKINGS		
SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION	AVAILABILITY C	F REPORT	
b. DECLASSIFICATION / DOWNGRADI	ECTE	Approve	d for publi	c release;	
SE	P 2 1 1987	distrib	ution unlim	ited.	
. PERFORMING ORGANIZATION REPORT		5. MONITORING	ORGANIZATION F ARO 21294.11	-MS	ER(S)
. NAME OF PERFORMING ORGANIZATION	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF M	ONITORING ORGA	NIZATION	
Rensselaer Polytechnic Inst.	U. S. A	Army Researc	ch Office		
c. ADDRESS (City, State, and ZIP Code)	7b. ADDRESS (Cit	ly, State, and ZIP	Code)		
Uepartment of Materials Engin RPL, Trov, ny 12180-3590	P. O. H	Box 12211	Darle NC	17700 2011	
	i	Keseard	in triangle	rark, NC	2//09-2211
a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMEN	T INSTRUMENT IC	DENTIFICATION	NUMBER
U. S. Army Research Office		DAAG29-84-K-0026			
c. ADDRESS (City, State, and ZIP Code)		10. SOURCE OF	FUNDING NUMBE	RS	
P. O. Box 12211 Research Triangle Park, NC 27	770 9- 2211	PROGRAM ELEMENT NO.	PROJECT NO.	NO.	WORK UNIT ACCESSION NO.
1 TITLE (Include Security Classification)					
The fine one secondy classification					
PROPERTIES OF REFRACTORY ME	ETALS PROCESSED	BY ENHANCED	SINTERING T	REATMENTS	(unclassified
PROPERTIES OF REFRACTORY ME	TALS PROCESSED	BY ENHANCED	SINTERING T	REATMENTS	(unclassifie
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farc	TALS PROCESSED	BY ENHANCED	SINTERING T	REATMENTS	(unclassifie
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farc 3a. TYPE OF REPORT Final Final FROM 3/	ETALS PROCESSED	BY ENHANCED 14. DATE OF REPO 1987 Ma	SINTERING T	REATMENTS	(unclassified GE COUNT 7
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farc 3a. TYPE OF REPORT Final 6 SUPPLEMENTARY NOTATION The view	ETALS PROCESSED	BY ENHANCED 14. DATE OF REPO 1987 Ma	SINTERING T ORT (Year, Month, Ly 29	REATMENTS	(unclassified GE COUNT 7
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farc 3a. TYPE OF REPORT Final 6 SUPPLEMENTARY NOTATION of the author(s) and should not	TALS PROCESSED	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s, an officia	SINTERING T ORT (Year, Month, by 29 Ontained in al Departmer	REATMENTS Day) 15. PA this repo	(unclassified GE COUNT 7 rt are those Army position
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farce 3a. TYPE OF REPORT Final 6 SUPPLEMENTARY NOTATION of the author(s) and should not policy. or decision. unless so 7 COSATI CODES	TALS PROCESSED	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s, an officia ther document continue on revers	SINTERING T ORT (Year, Month, y 29 ontained in al Department if necessary an	REATMENTS Day) 15. PA this repo it of the d identify by b	(unclassified GE COUNT 7 rt are those Army position
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farc 3a. TYPE OF REPORT Final 6 SUPPLEMENTARY NOTATION of the author(s) and should not policy. or decision. unless so 7 COSATI CODES FIELD GROUP SUB-GROUP	TALS PROCESSED DOQ DVERED /84 TO 2/87 opinions and/or t be construed a designated by of 18. SUBJECT TERMS (C Refractory Sintering	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia ther document continue on revers Metals, Act	SINTERING T ORT (Year, Month, by 29 Dontained in al Department if necessary and ivated Sint W-Ni-Fo	TREATMENTS Day) 15. PA this repo this repo the f the d identify by the eirng, Lie	(unclassified GE COUNT 7 rt are those Army position block number) quid Phase
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farce 3a. TYPE OF REPORT Final 6 SUPPLEMENTARY NOTATION of the author(s) and should not policy. or decision. unless so 7 COSATI CODES FIELD GROUP SUB-GROUP	TALS PROCESSED OOQ OVERED (84 TO 2/87 opinions and/or designated by 18. SUBJECT TERMS (C Refractory Sintering,	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia ther document continue on revers Metals, Act Heavy Alloys	SINTERING T ORT (Year, Month, y 29 ontained in al Department if necessary and ivated Sint i, W-Ni-Fe	TREATMENTS Day) 15. PAGE this report of the didentify by b eirng, Lie	(unclassified GE COUNT 7 rt are those Army position block number) quid Phase
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farce 3a. TYPE OF REPORT Final 6 SUPPLEMENTARY NOTATION 7 COSATI CODES FIELD 9 ABSTRACT (Continue on reverse if necessary	TALS PROCESSED DOQ DVERED (84 TO 2/87 opinions and/or be construed a designated by of 18. SUBJECT TERMS (C Refractory Sintering, and identify by block m	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia ther document fontinue on revers Metals, Act Heavy Alloys humber)	SINTERING T ORT (Year, Month, Ay 29 Dontained in al Department if necessary and ivated Sint i, W-Ni-Fe	REATMENTS Day) 15. PA this repo this repo tof the didentify by t eirng, Lin	(unclassified GE COUNT 7 rt are those Army position Nock number) quid Phase
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farce 3a. TYPE OF REPORT Final 6 SUPPLEMENTARY NOTATION 6 SUPPLEMENTARY NOTATION 7 COSATI CODES FIELD 9 ABSTRACT (Continue on reverse if necessary This investigation examinattempted to link activator ef	TALS PROCESSED OQ OVERED (84 TO 2/87 opinions and/or be construed a designated by o 18. SUBJECT TERMS (C Refractory Sintering, and identify by block m hed the sintering fects to sinter	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia ther docume Continue on revers Metals, Act Heavy Alloys number) g enhancemen ing kinetics	SINTERING T ORT (Year, Month, 14 29 Dontained in 11 Department 14 if necessary and 15 ivated Sint 15 , W-Ni-Fe 15 of refrace 16 microstrue	REATMENTS Day) 15. PA this repo this repo tof the didentify by t eirng, Lin tory meta	(unclassified GE COUNT 7 rt are those Army position Work number) quid Phase
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farce 3a. TYPE OF REPORT Final 6 SUPPLEMENTARY NOTATION of the author(s) and should not policy. or decision. unless so 7 COSATI CODES FIELD GROUP 9 ABSTRACT (Continue on reverse if necessary This investigation examinatempted to link activator ef Work was carried out predominated PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) 13b. TIME CO 13b. TIME CO 13b. TIME CO FROM3/ 13b. TIME CO FROM3/ F	TALS PROCESSED DOQ DVERED (84 TO 2/87 opinions and/or t be construed a designated by of 18. SUBJECT TERMS (C Refractory Sintering, and identify by block m hed the sintering fects to sinter ately on the W-N	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia ther document fontinue on revers Metals, Act Heavy Alloys number) g enhancement ing kinetics i-Fe heavy a	SINTERING T ORT (Year, Month, y 29 ontained in al Department if necessary and ivated Sint i, W-Ni-Fe t of refract microstru iloy system	TREATMENTS Day) 15. PAGE this repond tof the didentify by the eirng, Line tory metain cture and In add	(unclassified GE COUNT 7 rt are those Army position Nock number) quid Phase
PROPERTIES OF REFRACTORY ME PROPERTIES OF REFRACTORY ME PROPERTIES OF REFRACTORY ME PROPERTIES OF REFORT R. M. German and S. Farce 3a. TYPE OF REPORT Final 13b. TIME CO FROM	TALS PROCESSED OQ OVERED (84 TO 2/87 opinions and/or be construed a designated by o 18. SUBJECT TERMS (C Refractory Sintering, and identify by block m hed the sintering fects to sinter tely on the W-N ty improvement in	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia ther document continue on revers Metals, Act Heavy Alloys number) g enhancement ing kinetics i-Fe heavy allo	SINTERING T ORT (Year, Month, 1 29 ontained in 1 Department if necessary and ivated Sint , W-Ni-Fe it of refract , microstru lloy system bys could be	REATMENTS Day) 15 PA this repo tof the didentify by t eirng, Lin tory meta cture and . In add made poss	(unclassified GE COUNT 7 rt are those Army position Work number) quid Phase
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farce 3a. TYPE OF REPORT Final 6 SUPPLEMENTARY NOTATION of the author(s) and should not policy. or decision. unless so 7 COSATI CODES FIELD GROUP 9 ABSTRACT (Continue on reverse if necessary This investigation examinate attempted to link activator ef Work was carried out predomina it was recognized that propert understanding impurity-microst combined effect of processing	TALS PROCESSED OQ OVERED (84 TO 2/87 opinions and/or be construed a designated by of 18. SUBJECT TERMS (C Refractory Sintering, and identify by block in the sintering fects to sinter itely on the W-N ty improvement in tructure interact	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia ther document fortinue on revers Metals, Act Heavy Alloys mober) g enhancement ing kinetics i-Fe heavy allo tions, fract materials ch	SINTERING T ORT (Year, Month, y 29 ontained in al Department if necessary and ivated Sint i, W-Ni-Fe t of refract microstruction by system by could be our behavio	TREATMENTS Day) 15. PAGE this repond tof the didentify by b eirng, Lid tory meta cture and . In add made pose r, and fin	(unclassified GE COUNT 7 rt are those Army position Nock number) quid Phase Is and properties. ition, sible by hally the ification
PROPERTIES OF REFRACTORY ME PROPERTIES OF REFRACTORY ME PROPERTIES OF REFRACTORY ME PROPERTIES OF REFORT R. M. German and S. Farce 3a. TYPE OF REPORT Final Supplementary NOTATION The view, of the author(s) and should not policy. or decision. unless so field GROUP SUB-GROUP SUB-GROUP PABSTRACT (Continue on reverse if necessary This investigation examinate attempted to link activator ef Work was carried out predominadit was recognized that propert understanding impurity-microst combined effect of processing during liquid phase sintering.	TALS PROCESSED OQ OVERED (84 TO 2/87 opinions and/or be construed a designated by of 18. SUBJECT TERMS (C Refractory Sintering, and identify by block m hed the sintering fects to sinter tely on the W-N ty improvement in tructure interac conditions and a This report a	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia fher docume Continue on revers Metals, Act Heavy Alloys iumber) g enhancemen ing kinetics i-Fe heavy allo tions, fract materials ch ddresses eac	SINTERING T ORT (Year, Month, 1 29 ontained in al Department ivated Sint ivated Sint , W-Ni-Fe to f refract microstru loy system bys could be ure behavio aracteristi h of the ab	REATMENTS Day) 15. PAG this repo to f the d identify by t eirng, Lig tory meta cture and . In add made poss r, and fin cs on dens ove conce	(unclassified GE COUNT 7 rt are those Army position block number) quid Phase
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farce 3a. TYPE OF REPORT Final 6 SUPPLEMENTARY NOTATION of the author(s) and should not policy. or decision. unless so 7 COSATI CODES FIELD GROUP 9 ABSTRACT (Continue on reverse if necessary This investigation examinate attempted to link activator ef Work was carried out predominative it was recognized that propertunderstanding impurity-microst combined effect of processing during liquid phase sintering. presents an overview of the wo	TALS PROCESSED OQ OVERED (84 TO 2/87 opinions and/or designated by la subject terms (c Refractory Sintering, and identify by block in fects to sinter itely on the W-N ty improvement in cructure interac conditions and a This report ac ork to date.	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia ther document Tontinue on revers Metals, Act Heavy Alloys wober) g enhancement ing kinetics i-Fe heavy alloy tions, fract materials ch ddresses eac	SINTERING T ORT (Year, Month, y 29 ontained in al Department if necessary and ivated Sint i, W-Ni-Fe t of refract microstruction by system by could be ure behavio aracteristic h of the ab	TREATMENTS Day) 15. PAGE this repond tof the didentify by the eirng, Line tory metal cture and . In add . In add . In add . In add . In add . In add . Son dens ove concert	(unclassified GE COUNT 7 rt are those Army position Nock number) quid Phase Is and properties. ition, sible by hally the sification rns and
PROPERTIES OF REFRACTORY ME PROPERTIES OF REFRACTORY ME PROPERTIES OF REFRACTORY ME PROPERTIES OF REFORT R. M. German and S. Farce This Investigation and S. Farce FIELD GROUP The view, Of the author(s) and should not policy. OF decision. unless so COSATI CODES FIELD GROUP SUB-GROUP PROPERTIES OF REFORT This investigation examine attempted to link activator ef Work was carried out predomina it was recognized that propert understanding impurity-microst combined effect of processing during liquid phase sintering. presents an overview of the wo	TALS PROCESSED OQ OVERED (84	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia ther document continue on revers Metals, Act Heavy Alloys iumber) g enhancement ing kinetics i-Fe heavy allo tions, fract materials ch ddresses eac	SINTERING T ORT (Year, Month, 1 29 ontained in al Department ivated Sint ivated Sint ivat	REATMENTS Day) 15 PAG this repo to f the d identify by t eirng, Lig tory meta cture and . In add made pose r, and fin cs on dens ove concer	(unclassified GE COUNT 7 rt are those Army position Nock number) quid Phase
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farce 3a. TYPE OF REPORT Final 6 SUPPLEMENTARY NOTATION of the author(s) and should not policy. or decision. unless so 7 COSATI CODES FIELD GROUP 9 ABSTRACT (Continue on reverse if necessary This investigation examinate attempted to link activator ef Work was carried out predominative it was recognized that propertunderstanding impurity-microst combined effect of processing during liquid phase sintering. presents an overview of the wo	TALS PROCESSED OQ OVERED (84 TO 2/87 opinions and/or be construed a designated by or 18. SUBJECT TERMS (C Refractory Sintering, and identify by block m the sintering fects to sinter and identify by block m the sintering fects to sinter the sintering fects to sinter fects to sinter the sintering fects to sinter fects t	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia ther document continue on revers Metals, Act Heavy Alloys wober) g enhancement ing kinetics i-Fe heavy allow tions, fract materials ch ddresses eac	SINTERING T ORT (Year, Month, y 29 ontained in al Department if necessary and ivated Sint i, W-Ni-Fe t of refract microstru lloy system bys could be ure behavio baracteristi ch of the ab	TREATMENTS Day) 15. PAGE this repond to f the d identify by t eirng, Lin tory meta cture and . In add made poss r, and fin cs on dens ove concer	(unclassified GE COUNT 7 rt are those Army position Nock number) quid Phase Is and properties. ition, sible by nally the sification rns and
PROPERTIES OF REFRACTORY ME PROPERTIES OF REFRACTORY ME PROPERTIES OF REFRACTORY ME PROPERSONAL AUTHOR(S) R. M. German and S. Farce Table TIME CONT Reference of the second of the	TALS PROCESSED OQ OVERED (84 TO 2/87 opinions and/or be construed a designated by of 18. SUBJECT TERMS (C Refractory Sintering, and identify by block in fects to sinter and identify by block in the sintering fects to sinter and identify by block in the sinter in the sin the sinter in the sinter in the sinter in the sin the sinte	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia ther document continue on revers Metals, Act Heavy Alloys immber) g enhancement ing kinetics i-Fe heavy allo tions, fract materials ch ddresses eac	SINTERING T ORT (Year, Month, 1 29 ontained in al Department ivated Sint ivated Sint ivat	REATMENTS Day) 15 PA this repo tory meta didentify by t eirng, Lie tory meta cture and . In add made pose r, and fin cs on dens ove concer	(unclassified GE COUNT 7 rt are those Army position Nock number) quid Phase
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farce 3a. TYPE OF REPORT Final 13b. TIME CO FROM _3/ 6 SUPPLEMENTARY NOTATION The view, of the author(s) and should not policy. or decision. unless so 7 COSATI CODES FIELD GROUP SUB-GROUP 9 ABSTRACT (Continue on reverse if necessary This investigation examin attempted to link activator ef Work was carried out predomina it was recognized that propert understanding impurity-microst combined effect of processing during liquid phase sintering. presents an overview of the wo	opinions and/or be construed a designated by of the construed a designated by of the construed a designated by of the sintering, and identify by block m the sintering fects to sinter tely on the W-N ty improvement in tructure interac conditions and a This report a ork to date.	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia fher document continue on revers Metals, Act Heavy Alloys iumber) g enhancement ing kinetics i-Fe heavy allo tions, fract materials ch ddresses eac	SINTERING T ORT (Year, Month, 1 29 ontained in al Departmer ivated Sint ivated Sint , W-Ni-Fe t of refrac , microstru lloy system bys could be ure behavio aracteristi h of the ab	REATMENTS Day) 15. PAGE this repond tory metains didentify by b eirng, Ling tory metains cture and . In add made poss r, and fin cs on dens ove concer	(unclassified GE COUNT 7 rt are those Army position Wock number) quid Phase
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farce 3a. TYPE OF REPORT Final 6 SUPPLEMENTARY NOTATION of the author(s) and should not policy. or decision. unless so 7 COSATI CODES FIELD GROUP SUB-GROUP 9 ABSTRACT (Continue on reverse if necessary This investigation examinate attempted to link activator ef Work was carried out predomina it was recognized that propert understanding impurity-microst combined effect of processing during liquid phase sintering. presents an overview of the wo	TALS PROCESSED OQ OVERED (84 TO 2/87 opinions and/or be construed a designated by of Refractory Sintering, and identify by block in fects to sinter itely on the W-N ty improvement in tructure interact conditions and in This report a ork to date.	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia ther document continue on revers Metals, Act Heavy Alloys mober) g enhancement ing kinetics i-Fe heavy allo tions, fract materials ch ddresses eac 21. ABSTRACT SE Ur	SINTERING T ORT (Year, Month, 1 29 ontained in al Department ivated Sint ivated Sint ivat	TREATMENTS Day) 15. PAGE this repond to f the d identify by b eirng, Lid tory meta cture and . In add . In add . In add . In add . In add . In add . Ove concer . Ove concer . CATION	(unclassified GE COUNT 7 rt are those Army position Nock number) quid Phase Is and properties. ition, sible by hally the sification rns and
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farce 3a. TYPE OF REPORT Final 13b. TIME CO FROM	TALS PROCESSED OQ OVERED (84 TO 2/87 opinions and/or be construed a designated by o 18. SUBJECT TERMS (C Refractory Sintering, and identify by block in red the sintering fects to sinter and identify by block in red the sintering fects to sinter and identify by block in the sintering and identify by block in the sintering fects to sinter and identify by block in the sintering and identify by block in the sintering fects to sinter and identify by block in the sintering and identify by block in and identify by block in the sintering and identify by block in and identify by block in	BY ENHANCED 14. DATE OF REPO 1987 Ma findings co s an officia fher document continue on revers Metals, Act Heavy Alloys umber) g enhancement ing kinetics i-Fe heavy allo tions, fract materials ch ddresses eac 21. ABSTRACT SE UT 22b. TELEPHONE	SINTERING T ORT (Year, Month, 1 29 ontained in al Department ivated Sint ivated Sint ivat	REATMENTS Day) 15. PAR this report this report tory metal d identify by b eirng, Ling tory metal tory metal cture and . In add made pose r, and find ove concert Ove concert CATION e) 22c. OFFICE	(unclassified GE COUNT 7 rt are those Army position Nock number) quid Phase Is and properties. ition, sible by nally the sification rns and
PROPERTIES OF REFRACTORY ME 2 PERSONAL AUTHOR(S) R. M. German and S. Farce 3a. TYPE OF REPORT Final 13b. TIME co Final 13b. TIME co FROM _3/ 6 SUPPLEMENTARY NOTATION The view, of the author(s) and should not policy. or decision. unless so 7 COSATI CODES FIELD GROUP SUB-GROUP 9 ABSTRACT (Continue on reverse if necessary This investigation examin attempted to link activator ef Work was carried out predomina it was recognized that propert understanding impurity-microst combined effect of processing during liquid phase sintering. presents an overview of the wo 20 DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED SAME AS I 22a NAME OF RESPONSIBLE INDIVIDUAL 23 AMME OF RESPONSIBLE INDIVIDUAL 24 DEFORM 1473. BAMAR 83 AMME	TALS PROCESSED OQ OVERED (84 TO 2/87 opinions and/or be construed a designated by of responsed by of 18. SUBJECT TERMS (C Refractory Sintering, and identify by block in the sintering fects to sinter tely on the W-N ty improvement in tructure interact conditions and in This report and ork to date. RPT. DTIC USERS	BY ENHANCED 14. DATE OF REPC 1987 Ma findings co s an officia ther document Tontinue on revers Metals, Act Heavy Alloys waber) g enhancement ing kinetics i-Fe heavy alloys tions, fract materials ch ddresses eac 21. ABSTRACT SE UT 22b. TELEPHONE	SINTERING T ORT (Year, Month, 19 29 ontained in al Department if necessary an ivated Sint i, W-Ni-Fe t of refract microstru loy system bys could be ure behavio aracteristich of the ab CURITY CLASSIFIC iclassified (include Area Cod	Day) 15. PAR this report 15. PAR diagonal 16. In addition r, and fin 16. In addition ove concent 0. In addition (ATION 22c. OFFICE (CATION 22c. OFFICE	(unclassified GE COUNT 7 rt are those Army position Nock number) quid Phase Is and properties. ition, sible by hally the sification rns and SYMBOL

ARO 21294.11-MS

PROPERTIES OF REFRACTORY METALS PROCESSED BY ENHANCED SINTERING TREATMENTS

FINAL REPORT

R. M. German and S. Farooq

May 1987

U. S. ARMY RESEARCH OFFICE

INSPECTED

DAAG29-84-K-0026

RENSSELAER POLYTECHNIC INSTITUTE

Accesion For
NTIS CRA&I T DTIC TAB I Unanounced I Justification
By D. tot office (
Availability Codes
service difer Since constant
A-1

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

87 9 9 177

ር ፊሌ እን እሳር ሉና

THE VIEW, OPINIONS, AND/OR FINDINGS CONTAINED IN THIS REPORT ARE THOSE OF THE AUTHOR(S) AND SHOULD NOT BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION, POLICY, OR DECISION, UNLESS SO DESIGNATED BY OTHER DOCUMENTATION.

.

The aim of this investigation was to specifically examine the sintering enhancement of refractory metals and to link activator effects to sintering kinetics, microstructure and properties. In addition, it was recognized that property improvement in heavy alloys could be made possible by understanding impurity-microstructure interactions, fracture behavior, and finally the combined effect of processing conditions and material characteristics on densification during liquid phase sintering. The studies undertaken during the past three years addressed the above problems. While periodic reports described the results from such individual studies, this final report will present an overview of the work carried out to date.

The effect of processing conditions on as-sintered properties was studied. Initial studies were devoted to optimizing the sintering and heat treatment cycle in order to avoid extraneous variations and inconsistencies in the results. The optimum cycles used are:

Sintering Cycle - heat at 10 K/min to sintering temperature (1733-1773 K), hold at temperature for 30-60 minutes in hydrogen. Argon was used in the last 10 minutes of the sintering cycle and during cooling. The samples were cooled at 3 K/min through solidification temperature, and furnace cooled in argon.

<u>Heat Treatment Cycle</u> - heat at 10 K/min to 1373 K in argon, hold for 1 hour and quench in water.

It was found that sintering temperature and time affect grain size, dihedral angle and contiguity. These in turn affect the fracture behavior and hence the mechanical properties of heavy alloys. The manner in which microstructural features relate to each other was modelled theoretically. It was shown by such calculations that the contiguity was directly related to volume fraction of matrix phase and the dihedral angle. Briefly, small volume fractions of matrix phase and large dihedral angles increase contiguity. It was also shown that increased contiguity could significantly reduce the ductility.

From the experimental data it was apparent that the volume fraction did not change with sintering temperature and time. However, the dihedral angle increased with a decrease in sintering temperature. The above microstructural features were correlated with mechanical properties.

Based on the results of such experiments, it was felt that a better understanding of fracture behavior of heavy alloys was required. It was found that cracks initiate at the grain boundaries. This process of initiation was limited to the surface layers due to the absence of a triaxial stress field at the sample surface. Tensile fracture of heavy alloys is thus controlled by the accumulation of a critical amount of damage within the near surface region of the specimen. The first cracks appeared only at a few percent plastic strain and their frequency increased with an increase in tungsten content. The average crack size at a given plastic strain was found to be greater with lower tungsten content. A model was proposed in order to predict the fracture stress and strain in heavy alloys based upon microstructural characteristics. Fracture of a tensile bar is assumed to occur when a critical crack separation distance is reached within the near surface region. The crack separation distance depends upon both the number and size of the grain boundary cracks. These factors are determined by the strain, and microstructural variables such as volume fraction, grain size, dihedral angle, contiguity, etc. Based on the knowledge of true stress-strain behavior of these alloys, the proposed model can be used to predict mechanical properties.

It was also observed that the sintering atmosphere played an important role in determining densification behavior of these alloys. Water vapor evolution during sintering in a dry hydrogen atmosphere can lead to excessive porosity which is detrimental to heavy alloy properties. The effect of a pre-reduction treatment was shown to benefit in such cases. In the case of powders with high oxygen contents, the use of a wet hydrogen atmosphere in the presence of a liquid prevented the evolution of water vapor, resulting in high densities in the as-sintered product. Optimum processing of heavy alloys was thus shown to require careful dewpoint control. Theoretical modelling work had demonstrated that the sintering atmosphere controlled densification in the final stage of liquid phase sintering, and that a high diffusivity gas or vacuum sintering would give rise to rapid densification and hence higher as-sintered densities. Experiments using a vacuum resulted in excellent properties in the as-sintered material, generally exceeding those of conventionally sintered material.

Marginal improvements in heavy alloy properties can be obtained by changing the segregation patterns within these alloys. Theoretical modelling and experimental results clearly demonstrated that limited amount of segregation of elements like carbon, boron and nitrogen at interfaces would improve interface strengths and ductility. This improvement can be attributed both to a direct increase in bond strengths and indirectly to competitive segregation. It was also shown that the segregation of sulfur, phosphorus and oxygen resulted in reduced properties. Selective segregation can be successfully used to obtain substantial property improvement, particularly when the base level impurity concentration is far from optimal. The final part of this investigation was devoted to the study of liquid phase sintering in heavy alloys and the influence of material and processing parameters on densification. The variables studied were solubility of the major phase (W) in the additive, heating rate to sintering temperature and additive homogeneity. It has been shown that densification before and after the formation of the liquid phase is a strong function of all of the above parameters. Detailed theoretical and experimental studies are currently underway to better understand this effect.

In summary, this investigation has provided valuable insight into the processes and mechanisms that control densification behavior, microstructure, fracture and properties of heavy alloys. The effort has resulted in the development of optimal processing methods, theoretical models for prediction of sintering and mechanical behavior, and the ability to control properties with a great degree of consistency. In general it was shown that the final properties of heavy alloys are extremely structure sensitive, which is in turn related to the processing history.

PUBLICATIONS AND TECHNICAL REPORTS

"Recent Developments in the Sintering of Molybdenum", B. H. Rabin and R. M. German, Physical Metallurgy and Technology of Molybdenum and its Alloys, AMAX Research Center, Ann Arbor, MI, 1985, pp.101-105.

"Retarded Grain Boundary Mobility in Activated Sintered Molybdenum", P. E. Zovas and R. M. German, Metallurgical Transactions A, 1984, vol.15A, pp.1103-1110.

"Characterization of Liquid Phase Sintered Composite Microstructures", B. H. Rabin, A. Bose and R. M. German, Microstructural Science.

"Analysis of High Tungsten Content Heavy Alloys", R. M. German and L. L. Bourguignon, Powder Metallurgy in Defense Technology, 1985, vol.6, pp.117-131.

"The Effect of the Binder Phase Melting Temperature on Enhanced Sintering", R. M. German, Metallurgical Transactions A, 1986, vol.17A, pp.903-906. "Microstructure Limitations of High Tungsten Content Heavy Alloys", R. M. German, L. L. Bourguignon and B. H. Rabin, Journal of Metals, 1985, vol.37, 8, pp.36-39.

"The Two-Dimensional Connectivity of Liquid Phase Sintered Microstructures", R. M. German, Metallurgical Transactions A, 1987, vol.18A, pp.909-914.

"Enhanced Sintering through Second Phase Additions", R. M. German and B. H. Rabin, Powder Metallurgy, 1985, vol.28, pp.7-11.

"The Contiguity of Liquid Phase Sintered Microstructures", R. M. German, Metallurgical Transactions, 1985, vol.16A, pp.1247-1252.

"Liquid Phase Sintering of Tungsten Heavy Alloys in Vacuum", A. Bose, B. H. Rabin and R. M. German, Progress in Powder Metallurgy, 1986, vol.42, pp.557-567.

"Formation of Necklace Microstructures during Liquid Phase Sintering", R. M. German, International Journal of Powder Metallurgy, 1986, vol.41, pp.183-188.

"Theory of Liquid Phase Sintering: Model Experiments on the W-Ni-Fe Heavy Alloy System", S. Farooq, A. Bose and R. M. German, Annual Powder Metallurgy Conference, APMI-MPIF, 1987, Dallas.

PARTICIPATING SCIENTIFIC PERSONNEL

Dr. R. M. German - Principal Investigator.

Dr. A. Bose - Post Doctoral Fellow (part time).

Dr. B. H. Rabin - Graduate Research Assistant, awarded a Ph.D.

S. Faroog - Graduate Research Assistant, Ph.D. candidate.

J. Bourguignon - Undergraduate assistant, B.S. candidate.

R. Iacocca - Undergraduate assistant, B.S. candidate.

