Universiti Malaysia PAHANG
Engineering • Technology • Creativity

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

DR. SYARIFAH NUR AQIDA SYED AHMAD
ASSOCIATE PROFESSOR
DEPARTMENT OF MECHANICAL ENGINEERING
COLLEGE OF ENGINEERING
UNIVERSITI MALAYSIA PAHANG
LEBUHRAYA TUN RAZAK
26300 GAMBANG, KUANTAN, PAHANG
TEL: +609-549 2276 FAX: +09-5492689

(Supervisor's Signature)

Full Name : DR. SYARIFAH NUR AQIDA BINTI SYED AHMAD

Position : ASSOCIATE PROFESSOR

Date : 01 DECEMBER 2021

Universiti Malaysia PAHANG

Engineering • Technology • Creativity

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

(Student's Signature)

Full Name : FAZLIANA BINTI FAUZUN

ID Number : PMM16006

Date : 01 DECEMBER 2021

LASER CLADDING OF TOOL STEEL FOR GRAIN BOUNDARY STABILITY

FAZLIANA BINTI FAUZUN

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

College of Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2021

"In the name of ALLAH, the Most Beneficent, the Most Merciful"

This thesis is specially dedicated to:

Beloved husband, father and mother;

MOHD. HERZWAN BIN HAMZAH
FAUZUN BIN YAHYA
SHAHRIAH BINTI HAMZAH

for your love, trust and support along my journey as a student. You are my source of inspiration and spirit for me along my study and life.

ACKNOWLEDGEMENTS

Foremost, I would like to express my deep gratitude to my research supervisor, Associate Professor Dr. Syarifah Nur Aqida binti Syed Ahmad for the patient guidance, sharing germinal ideas, and constantly support in completing this thesis. My sincerely thanks given to her for the time spent to correct my mistakes and giving useful critiques of my research work. Without her guidance, this thesis would not have been completed.

I also would like to express very special thanks to Senior Lecturer Dr. Izwan Ismail from Manufacturing and Mechatronic Engineering Technology Faculty, Universiti Malaysia Pahang (UMP) and Mr. Abdul Fattah Mohd. Tahir, Lecturer of Automative Manufacturing Department from Kolej Kemahiran Tingi MARA Kuantan (KKTM) for their ideas, suggestions, help and training throughout the study. Also not forgotten, I would like to extend my thanks to the staff and technicians of the laboratory of Mechanical and Automotive Engineering Technology Faculty (FTKMA), Central Laboratory, Center of Excellence for Advance Research in Fluid Flow (CARIFF) in UMP and Mechanical and Manufacturing Engineering Faculty in Universiti Tun Hussein Onn Malaysia (UTHM) for their supporting ideas and helped especially in technical aspects during this thesis writing.

I would like to acknowledge main support for the research funding from the Ministry of Education Malaysia under Fundamental Research Grant Scheme (FRGS) with the grant number FRGS/1/2016/TK03/UMP/02/4. I also would like to express my sincere gratitude to Pusat Penyelidikan Dan Inovasi, UMP for granting me under Post Graduate Research Scheme and Ministry of Education Malaysia through MyBrain15 program which supports my study fees. My sincere thanks also go to all friends especially my fellow friends from postgraduate students of FTKMA and College of Engineering, UMP for their help and support along this study. Lastly, I would like to thank anyone who kindly helped me along the experiment and completion of this thesis.

I acknowledge my sincere indebtedness and gratitude to my husband Mohd. Herzwan Hamzah, my parents Fauzun bin Yahya and Shahriah binti Hamzah for their love, dream and sacrifice throughout my life. I cannot find appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. I am also grateful to my siblings Nursyafira, Muhammad Fadhli and Fariza for their continuous support and understanding that were inevitable to make this research done. I attribute the level of my PhD to my family for their enthusiastic encouragement. Finally, I dedicated this thesis to my beloved son, Muhammad Ali bin Mohd. Herzwan.

ABSTRAK

Teknologi salutan laser adalah salah satu teknik yang berkesan untuk meningkatkan kestabilan haba keluli. Penambahan zarah WC boleh menghalang pergerakan sempadan bijian dalam mikrostuktur yang seringkali terjadi pada strktur yang diubah pada persekitaran suhu tinggi. Tesis ini membentangkan kajian eksperimen tentang salutan laser menggunakan serbuk tungsten karbida (WC) terhadap keluli karbon tinggi H13 untuk meningkatkan kestabilan mikrostruktur. Matlamat utama adalah untuk menghasilkan lapisan gabungan WC dengan penambahbaikan sifat yang sesuai untuk aplikasi suhu tinggi terutamanya dalam industri *die-casting*. Salutan laser dijalankan dengan menggunakan sistem laser bergelombang 1.06 μm. Eksperimen pertama (DOE 1) telah dijalankan dengan menggunakan sistem laser jenis Nd:YAG manakala eksperimen seterusnya (DOE 2, DOE 3 dan DOE 4) menggunakan sistem laser fiber. Lapisan serbuk WC dicampurkan dengan cecair sodium silikat dan 4% PVA sebagai pengikat dan diletakkan diatas keluli sebelum dilaser. DOE 1 mempunyai 16 sampel untuk kajian taburan zarah WC dalam mikrostruktur lapisan gabungan. Manakala DOE 2 dan DOE 3 pula dijalankan untuk mengkaji perbezaan penggunaan pengikat dan juga kesan penyerapan tenaga laser kepada mikrostruktur. DOE 4 yang terakhir dijalankan dengan rekabentuk eksperimen Box-Behnken yang menghasilkan 17 sampel. Tiga faktor yang digunakan adalah kuasa puncak, frekuensi denyut berulang (PRF) dan kelajuan laser dengan julat masing-masing adalah antara 1.8 hingga 2.0 kW, 15 hingga 30 Hz dan 315 hingga 630 mm/min. Analisis statistik telah dijalankan pada DOE 4 untuk mendapatkan rekabentuk eksperimen yang optimum. Semua sampel dianalisis untuk ujian kekerasan, ketebalan lapisan gabungan WC, perubahan elemen dalam mirostruktur melalui ujian EDXS dan tranformasi fasa melalui ujian XRD. Selain itu, ujian kelesuan haba telah dijalankan mengikut process d*ie-casting* bagi tujuan kajian kestabilan haba lapisan gabungan WC. Ujian kehausan haba merangkumi proses celupan dalam logam aluminium cair, penyejukan diudara dan yang terakhir adalah penyejukan dalam air pada suhu bilik. Ujian ini dijalankan sebanyak 1000, 3000 dan 5000 kitaran. Sampel ujian dianalisis untuk menentukan kadar kehausan struktur lapisan gabungan WC. Simulasi ujian kehausan haba turut dijalankan dengan perisian ABAQUS untuk kajian taburan haba dan tekanan pada permukaan lapisan gabungan WC. Keputusan DOE 4 menunjukkan taburan zarah WC yang homogen berjaya dicapai dalam mikrostruktur lapisan gabungan WC dengan sifat kekerasan maksima sebanyak 2300 HV. Gabungan zarah WC berjaya meningkatkan kekerasan struktur sebanyak 70%. Analisis EDXS menunjukkan elemen W daripada zarah WC yang terlarut telah meresap ke sempadan bijian lalu menguatkan sistem mirostruktur. Empat fasa telah dikenalpasti melalui analysis XRD iaitu α-Fe, γ-Fe, tungsten (W), tungsten karbida (W2C) dan qusongite (WC). Ujian kehausan haba menunjukkan kadar kekurangan jisim disebabkan permukaan terhakis yang bertambah seiring dengan jumlah kitaran. Retakan juga terhasil seiring dengan penambahan jumlah kitaran ujian. Selain itu, empat fasa baru terhasil pada sampel yang telah haus haba adalah NiFeAlO4, CoWO4 and FeWO4. Keputusan ini disebabkan pengoksidaan dan resapan atom pada permukaan lapisan gabungan WC. Sifat kekerasan sampel yang haus telah menurun sebanyak 23 %. Simulasi haba menunjukkan parameter kehausan haba mempunyai kesan yang nyata terhadap suhu dan taburan tekanan pada sampel laser lapisan. Analisis statistik menemukan rekabentuk eksperimen yang optimum pada 0.901. Penemuan dalam tesis ini adalah penting untuk penambahbaikan kestabilan haba suatu permukaan pada persekitaran kerja suhu tinggi, terutamanya dalam industri *die-casting*.

ABSTRACT

Laser cladding is one of the best methods to modify the steel surface for enhanced thermal stability properties. Added carbide particle impeded the grain boundary migration which often occurred in metastable modified microstructure at high working temperature. In this thesis, an experimental study of laser cladding on H13 tool steel with tungsten carbide (WC) particles addition is presented. The aim is to produce WC cladded layer with enhanced properties for high temperature applications specifically in die-casting. The laser cladding was conducted using laser systems of 1.06 μm wavelength. The preliminary experiment (DOE 1) was processed using the Nd:YAG laser while other DOE (DOE 2, DOE 3 and DOE 4) with fibre laser. The cladded layer of WC particles with sodium silicate and 4% PVA binder's agent was preplaced prior to laser processing. DOE 1 consists of 16 samples investigates the powder distribution on cladded layer at different parameter settings. Meanwhile, DOE 2 and DOE 3 investigate the effect of binders to powder distribution ratio on clad layer thickness as well as laser energy absorption of the surface. DOE 4 was developed using Box-Behnken design to study the powder distribution and grain evolution of cladded layer. All samples were characterised for hardness properties, depth of cladded layer, elemental changes in microstructure by EDXS analysis and phase transformation by XRD analysis. Thermal wear test that simulated die-casting environment was conducted to investigate the thermal stability of cladded layer. The thermal wear test involves cyclic heating of cladded samples in molten aluminium alloy at an elevated temperature range of 800-850 °C and quenching in room temperature water bath, for 1000, 3000 and 5000 cycles. Sample characterisation was carried out to measure the properties of thermally worn cladded layer. A thermal simulation was developed using ABAQUS software to study the distribution of thermal stress and temperature within cladded layer. The statistical analysis was conducted for DOE 4 with design optimisation. From the findings, powder distribution within clad layer improvement was achieved in samples of DOE 4. The resulted WC particle distribution in DOE 4 shows significant microhardness increment up to 70 %, due to high hardness carbides within the iron matrix. The EDXS analysis indicates WC particle dissolution in the clad layer where W element diffused to the grain boundary, thus strengthen the iron matrix. Four main phases were detected from XRD analysis namely; α-Fe, γ-Fe, tungsten (W), tungsten carbide (W2C) and qusongite (WC). From the thermal wear test, mass loss and volume of the eroded surface of cladded samples shows an increment with an increasing number of thermal wear cycles. Crack formation and propagation were observed on the thermally worn cladded samples with the increasing number of thermal wear cycles. Phases like NiFeAlO4, CoWO4 and FeWO4 were diffracted on the thermally worn sample surface in addition to the existing phases (α-Fe, γ-Fe and W2C) indicating oxidation and atomic diffusion occurred on the surface affected by thermal cyclic. Overall, laser clad samples hardness properties reduction was 23 %. Thermal modelling shows significant effect of thermal fatigue parameter towards temperature and stress distribution on cladded sample. The statistical analysis generated optimised design at 0.901. These findings are significant to enhance surface properties especially thermal stability at high working temperature for dies and high wear resistant applications.

TABLE OF CONTENT

DECLARATION	
TITLE PAGE	
DEDICATION	
ACKNOWLEDGEMENTS	**ii**
ABSTRAK	**iii**
ABSTRACT	**iv**
TABLE OF CONTENT	**v**
LIST OF TABLES	**ix**
LIST OF FIGURES	**x**
LIST OF SYMBOLS	**xiv**
LIST OF ABBREVIATIONS	**xv**
CHAPTER 1 INTRODUCTION	**1**
1.1 Introduction	1
1.2 Problem statement	4
1.3 Research motivation	6
1.4 Research hypothesis	6
1.5 Research objectives	6
1.6 Scope of study	7
1.7 Thesis overview	8
CHAPTER 2 LITERATURE REVIEW	**9**
2.1 Introduction	9
2.2 Dies failure in casting processing	9
2.3 Laser surface cladding techniques	12
2.3.1 Cladding processing methods at different types laser, materials and powders	15

2.3.2 Laser cladding on different materials 16
2.3.3 WC particle addition in laser cladding 18
2.3.4 Powder addition technique in laser cladding 23
2.3.5 Effect of particles size to cladded layer 24
2.3.6 Parameters effect on particle distribution 27
2.4 Grain boundary migration 29
2.4.1 Metastable phase 29
2.4.2 Particle movement mechanism 31
2.5 Thermal wear performance 32
2.5.1 Metallurgical study 32
2.5.2 Effect of microhardness properties 37
2.5.3 Surface erosion and mass reduction 38
2.5.4 Thermal fatigue testing method 39
2.6 Thermal stress modelling 41
2.7 Summary 41

CHAPTER 3 METHODOLOGY **43**
3.1 Introduction 43
3.2 Material and sample preparation 44
3.2.1 Preplace method 45
3.3 Laser Cladding Processing 47
3.3.1 Nd:YAG laser cladding processing 48
3.3.2 Fibre laser cladding processing 50
3.3.3 Design of experiment 52
3.4 Characterisation techniques 58
3.4.1 FESEM analysis for metallographic study 58
3.4.2 Surface Morphology Analysis 59

3.4.3 XRD Phase Analysis 59

3.4.4 Microhardness properties 60

3.5 Thermal wear test 61

3.6 Thermal wear simulation 64

3.6.1 Part geometry and meshing 64

3.6.2 Material properties 65

3.6.3 Cycle step, boundary condition and output 66

3.7 Statistical Analysis and Design Optimization 68

CHAPTER 4 RESULTS AND DISCUSSION 70

4.1 Introduction 70

4.2 Metallographic Study 71

4.2.1 Grain structure evolution, WC particle distribution and dissolution. 71

4.2.2 Defects in clad layer 77

4.2.3 Effect of WC particle distribution with different binders' agent 78

4.2.4 Improved WC Particle Distribution in Clad Layer 80

4.2.5 Particle distribution differences between all DOE. 87

4.3 Energy Dispersive X-Ray Spectroscopy (EDXS) analysis 89

4.4 X-Ray Diffraction (XRD) analysis 93

4.5 Microhardness properties 98

4.6 Thermal wear analysis 100

4.6.1 Surface morphology 100

4.6.2 Metallurgical study 104

4.6.3 Thermal Stability 110

4.7 Thermal wear simulation 111

4.7.1 FE simulation validation 111

4.7.2 Temperature evolution 113

4.7.3 Thermal stress distribution 114

4.8 Statistical analysis of DOE 4 119

4.8.1 Hardness properties of WC cladded samples. 119

4.8.2 Tungsten carbide (WC) particle distribution on cladded samples. 121

4.8.3 Depth of modified clad layer properties. 124

4.8.4 Design optimisation 126

4.9 Summary 128

CHAPTER 5 CONCLUSION 130

5.1 Conclusion 130

5.2 The laser cladding on HWTS with mixed size of WC particles 130

5.3 Thermal stability performance of laser cladding 130

5.4 Thermal wear simulation 131

5.5 Statistical analysis 131

5.6 Recommendation 131

REFERENCES 133

APPENDICES 149

APPENDIX A: LASER PARAMETERS CALCULATION FORMULA. 150

APPENDIX B: PART PARTITIONED FOR H13 CLADDED SURFACE AND IMMERSION REGION IN THERMAL MODELLING. 152

APPENDIX C: THE ERROR CALCULATION METHOD FOR FE THERMAL MODELLING 153

APPENDIX D: THE CONTOUR PLOT OF OPTIMISED MICROHARDNESS AT (A), WC DISTRIBUTION AREA AT (B) AND DEPTH OF CLAD LAYER AT (C) 154

LIST OF PUBLICATION 155

REFERENCES

Abdulhadi, H. A. (2017). Thermal Wear Behaviour Of H13 Tool Steel In Die Casting Process. Thesis Doctor of Philosophy (PhD), Universiti Malaysia Pahang.

Abdulhadi, H. A., S. N. A. S. Ahmad, I. Ismail, M. Ishak and G. R. Mohammed (2017). "Thermally-Induced Crack Evaluation in H13 Tool Steel." Metals **7**(11): 475.

Abioye, T. E., P. K. Farayibi, D. G. McCartney and A. T. Clare (2016). "Effect of carbide dissolution on the corrosion performance of tungsten carbide reinforced Inconel 625 wire laser coating." Journal of Materials Processing Technology **231**: 89-99.

Ageev, E. I., Y. M. Andreeva, A. A. Ionin, N. S. Kashaev, S. I. Kudryashov, N. V. Nikonorov, R. K. Nuryev, A. A. Petrov, A. A. Rudenko, A. A. Samokhvalov, I. N. Saraeva and V. P. Veiko (2020). "Single-shot femtosecond laser processing of Al-alloy surface: An interplay between Mbar shock waves, enhanced microhardness, residual stresses, and chemical modification." Optics & Laser Technology **126**: 106131.

Ahmadi-Pidani, R., R. Shoja-Razavi, R. Mozafarinia and H. Jamali (2012). "Improving the thermal shock resistance of plasma sprayed CYSZ thermal barrier coatings by laser surface modification." Optics and Lasers in Engineering **50**(5): 780-786.

Ahmadi-Pidani, R., R. Shoja-Razavi, R. Mozafarinia and H. Jamali (2013). "Laser surface modification of plasma sprayed CYSZ thermal barrier coatings." Ceramics International **39**(3): 2473-2480.

Al-Hamdani, K. S., J. W. Murray, T. Hussain and A. T. Clare (2020). "Controlling ceramic-reinforcement distribution in laser cladding of MMCs." Surface and Coatings Technology **381**: 125128.

Allain, S., S. Gaudez, G. Geandier, J. C. Hell, M. Goune, F. Danoix, S. Michel, S. Aoued and A. Poulon (2017). "Internal stresses and carbon enrichment in austenite of Quenching & Partitioning steels from High Energy X-Ray diffraction experiments." Materials Science and Engineering: A **710**.

Amado, J. M., J. Montero, M. J. Tobar and A. Yáñez (2014). "Laser Cladding of Ni-WC Layers with Graded WC Content." Physics Procedia **56**: 269-275.

Annie Lau Sheng, I. I. (2019). Thermal Fatige of Laser Modified Tool Steels Mould Surface at High Temperature. Master Degree, Univeristi Malaysia Pahang.

Aqida, S. N., M. Maurel, D. Brabazon, S. Naher and M. Rosso (2009). "Thermal stability of laser treated die material for semi-solid metal forming." International Journal of Material Forming **2**(1): 761-764.

Aqida, S. N., S. Naher and D. Brabazon (2011). Laser surface modification of H13 die steel using different laser spot sizes. AIP Conference Proceedings.

Aqida, S. N., S. Naher, M. Maurel and D. Brabazon (2008). "An overview of laser surface modification of die steels."

Armattoe, K. M., C. Bouby, M. Haboussi and T. Ben Zineb (2016). "Modeling of latent heat effects on phase transformation in shape memory alloy thin structures." International Journal of Solids and Structures **88-89**: 283-295.

Avilés, R., J. Albizuri, A. Lamikiz, E. Ukar and A. Avilés (2011). "Influence of laser polishing on the high cycle fatigue strength of medium carbon AISI 1045 steel." International Journal of Fatigue **33**(11): 1477-1489.

Bajkowski, A. S., R. Kulchytsky-Zhyhailo and S. J. Matysiak (2019). "The problem of a periodically two-layered coating on a homogeneous half-space heated by moving heat fluxes." International Communications in Heat and Mass Transfer **103**: 110-116.

Balci, M. N. and S. Dag (2020). "Moving contact problems involving a rigid punch and a functionally graded coating." Applied Mathematical Modelling **81**: 855-886.

Bartkowski, D., A. Młynarczak, A. Piasecki, B. Dudziak, M. Gościański and A. Bartkowska (2015). "Microstructure, microhardness and corrosion resistance of Stellite-6 coatings reinforced with WC particles using laser cladding." Optics & Laser Technology **68**: 191-201.

Binesh, B. and M. Aghaie-Khafri (2016). "RUE-based semi-solid processing: Microstructure evolution and effective parameters." Materials & Design **95**: 268-286.

Bombač, D., M. Gintalas, G. Kugler and M. Terčelj (2019). "Thermal fatigue behaviour of Fe-1.7C-11.3Cr-1.9Ni-1.2Mo roller steel in temperature range 500–700 °C." International Journal of Fatigue **121**: 98-111.

Cadenas, M., R. Vijande, H. J. Montes and J. M. Sierra (1997). "Wear behaviour of laser cladded and plasma sprayed WC□Co coatings." Wear **212**(2): 244-253.

Chander, S. and V. Chawla (2017). "Failure of Hot Forging Dies –An Updated Perspective." Materials Today: Proceedings **4**(2, Part A): 1147-1157.

Chang, F., B. Cai, C. Zhang, B. Huang, S. Li and P. Dai (2019). "Thermal stability and oxidation resistance of FeCrxCoNiB high-entropy alloys coatings by laser cladding." Surface and Coatings Technology **359**: 132-140.

Chen, B., J. Jiang and F. P. E. Dunne (2018). "Is stored energy density the primary meso-scale mechanistic driver for fatigue crack nucleation?" International Journal of Plasticity **101**: 213-229.

Chen, L., B. Richter, X. Zhang, X. Ren and F. E. Pfefferkorn (2020). "Modification of surface characteristics and electrochemical corrosion behavior of laser powder bed fused stainless-steel 316L after laser polishing." Additive Manufacturing **32**: 101013.

Chen, W., C. Chen, X. Zi, X. Cheng, X. Zhang, Y. C. Lin and K. Zhou (2018). "Controlling the microstructure and mechanical properties of a metastable β titanium alloy by selective laser melting." Materials Science and Engineering: A **726**: 240-250.

Chen, Y., F. Lu, K. Zhang, P. Nie, S. R. Elmi Hosseini, K. Feng and Z. Li (2016). "Dendritic microstructure and hot cracking of laser additive manufactured Inconel 718 under improved base cooling." Journal of Alloys and Compounds **670**: 312-321.

Chien, C. S., T. Y. Liao, T. F. Hong, T. Y. Kuo, J. L. Wu and T. M. Lee (2011). "Investigation into microstructural properties of fluorapatite Nd-YAG laser clad coatings with PVA and WG binders." Surface and Coatings Technology **205**(10): 3141-3146.

Chyrkin, A., R. Pillai, H. Ackermann, H. Hattendorf, S. Richter, W. Nowak, D. Grüner and W. J. Quadakkers (2015). "Modeling carbide dissolution in alloy 602 CA during high temperature oxidation." Corrosion Science **96**: 32-41.

Cordaro, L. (2014). "Aluminum Die Casting- Surface Finish Guidelines." from https://diecasting.com/blog/2014/04/15/aluminum-die-casting-surface-finish-guidelines/.

Cordaro, L. (2014). "Aluminum Die Casting – Die Life Considerations." from https://diecasting.com/blog/2014/03/11/aluminum-die-casting-die-life-considerations/.

Custompart.net. (2008). "Die casting." from https://www.custompartnet.com/wu/die-casting#process_cycle.

Dadoo, A. and S. M. A. Boutorabi (2020). "Correlation between pulsed laser parameters and MC carbide morphology in H13 tool steel/TiC composite coating." Optics & Laser Technology **127**: 106120.

Dadoo, A., S. M. A. Boutorabi and S. Kheirandish (2019). "Effect of titanium carbide concentration on the morphology of MC carbides in pulsed laser surface alloyed AISI H13 tool steel." Optics & Laser Technology **112**: 236-244.

Das Bakshi, S., D. Sinha and S. Ghosh Chowdhury (2018). "Anisotropic broadening of XRD peaks of α'-Fe: Williamson-Hall and Warren-Averbach analysis using full width at half maximum (FWHM) and integral breadth (IB)." Materials Characterization **142**: 144-153.

de Oliveira, H. M. R., H. Louche, E. N. D. Grassi and D. Favier (2020). "Specific forward/reverse latent heat and martensite fraction measurement during superelastic deformation of nanostructured NiTi wires." Materials Science and Engineering: A **774**: 138928.

Den Broeder, F. J. A. (1972). "Interface reaction and a special form of grain boundary diffusion in the Cr-W system." Acta Metallurgica **20**(3): 319-332.

Dong, H., Y. Z. Chen, K. Wang, G. B. Shan, Z. R. Zhang, W. X. Zhang and F. Liu (2020). "Modeling remelting induced destabilization of lamellar eutectic structure in an undercooled Ni-18.7 at.% Sn eutectic alloy." Journal of Alloys and Compounds **826**: 154018.

Dong, S., C. Zhang, L. Zhang, J. Cai, P. Lv, Y. Jin and Q. Guan (2018). "Microstructure and properties of Cu-Cr powder metallurgical alloy induced by high-current pulsed electron beam." Journal of Alloys and Compounds **755**: 251-256.

Du, B.-C., Y.-L. He, Z.-J. Zheng and Z.-D. Cheng (2016). "Analysis of thermal stress and fatigue fracture for the solar tower molten salt receiver." Applied Thermal Engineering **99**: 741-750.

Dunne, F. P. E., A. J. Wilkinson and R. Allen (2007). "Experimental and computational studies of low cycle fatigue crack nucleation in a polycrystal." International Journal of Plasticity **23**(2): 273-295.

Dutta Majumdar, J., A. K. Nath and I. Manna (2010). "Studies on laser surface melting of tool steel — Part II: Mechanical properties of the surface." Surface and Coatings Technology **204**(9–10): 1326-1329.

Erfanmanesh, M., R. Shoja-Razavi, H. Abdollah-Pour, H. Mohammadian-Semnani, M. Barekat and S. H. Hashemi (2019). "Friction and wear behavior of laser cladded WC-Co and Ni/WC-Co deposits at high temperature." International Journal of Refractory Metals and Hard Materials **81**: 137-148.

Fan, P. and G. Zhang (2020). "Study on process optimization of WC-Co50 cermet composite coating by laser cladding." International Journal of Refractory Metals and Hard Materials **87**: 105133.

Fang, Q., W. Bai, J. Yang, X. Xu, G. Li, N. Shi, M. Xiong and H. Rong (2009). "Qusongite (WC): A new mineral." American Mineralogist **94**(2-3): 387-390.

Fang, S., T. Herrmann, A. Rosenkranz, C. Gachot, F. G. Marro, F. Mücklich, L. Llanes and D. Bähre (2016). "Tribological Performance of Laser Patterned Cemented Tungsten Carbide Parts." Procedia CIRP **42**: 439-443.

Farahmand, P. and R. Kovacevic (2015). "Corrosion and wear behavior of laser cladded Ni–WC coatings." Surface and Coatings Technology **276**: 121-135.

Farahmand, P. and R. Kovacevic (2015). "Laser cladding assisted with an induction heater (LCAIH) of Ni–60%WC coating." Journal of Materials Processing Technology **222**: 244-258.

Farahmand, P., S. Liu, Z. Zhang and R. Kovacevic (2014). "Laser cladding assisted by induction heating of Ni–WC composite enhanced by nano-WC and La2O3." Ceramics International **40**(10, Part A): 15421-15438.

Fauzun, F., M. Wahab and S. N. Aqida (2013). "Laser Surface Modification of AISI 1025 Low Carbon Steel Using Pulsed Nd: YAG Laser for Enhance Surface Properties." Key Engineering Materials **554**: 596-602.

Fazliana, F., S. N. Aqida, S. Ahmad, S. Naher, D. Brabazon, F. Calosso and M. Rosso (2013). "Effects of Thermal Fatigue on Laser Modified H13 Die Steel."

Fernández, M. R., A. García, J. M. Cuetos, R. González, A. Noriega and M. Cadenas (2015). "Effect of actual WC content on the reciprocating wear of a laser cladding NiCrBSi alloy reinforced with WC." Wear **324–325**: 80-89.

Galicki, D., B. C. Chakoumakos, S. P. Ringer, M. Eizadjou, C. J. Rawn, K. Nomoto and S. S. Babu (2020). "On the formation of spherical metastable BCC single crystal spatter particles during laser powder bed fusion." Materialia **9**: 100584.

Gall, K., N. Yang, M. Horstemeyer, D. L. McDowell and J. Fan (2000). "The influence of modified intermetallics and Si particles on fatigue crack paths in a cast A356 Al alloy." Fatigue & Fracture of Engineering Materials & Structures **23**: 159-172.

Ganeev, R. A. (2002). "Low-power laser hardening of steels." Journal of Materials Processing Technology **121**(2–3): 414-419.

Gao, J., C. Wu, Y. Hao, X. Xu and L. Guo (2020). "Numerical simulation and experimental investigation on three-dimensional modelling of single-track geometry and temperature evolution by laser cladding." Optics & Laser Technology **129**: 106287.

Grosdidier, T., J. X. Zou, B. Bolle, S. Z. Hao and C. Dong (2010). "Grain refinement, hardening and metastable phase formation by high current pulsed electron beam (HCPEB) treatment under heating and melting modes." Journal of Alloys and Compounds **504**: S508-S511.

Grüning, A., M. Lebsanft and B. Scholtes (2010). "Cyclic stress–strain behavior and damage of tool steel AISI H11 under isothermal and thermal fatigue conditions." Materials Science and Engineering: A **527**(7): 1979-1985.

Guo, L., S. Huang, L. Zhang and P. Jia (2018). "The interface crack problem for a functionally graded coating-substrate structure with general coating properties." International Journal of Solids and Structures **146**: 136-153.

Hahnenberger, F., M. Smaga and D. Eifler (2014). "Microstructural investigation of the fatigue behavior and phase transformation in metastable austenitic steels at ambient and lower temperatures." International Journal of Fatigue **69**: 36-48.

He, M., Z. Zhentai, F. Shi, D. Guo and J. Yu (2020). "A novel crack healing technique in a low carbon steel by cyclic phase transformation heat treatment: The process and mechanism." Materials Science and Engineering: A **772**: 138712.

Hidalgo, J., R. M. Huizenga, K. O. Findley and M. J. Santofimia (2019). "Interplay between metastable phases controls strength and ductility in steels." Materials Science and Engineering: A **745**: 185-194.

Horstemeyer, M. F., N. Yang, K. Gall, D. L. McDowell, J. Fan and P. M. Gullett (2004). "High cycle fatigue of a die cast AZ91E-T4 magnesium alloy." Acta Materialia **52**(5): 1327-1336.

Hu, J. and H. Xu (2016). "Friction and wear behavior analysis of the stainless steel surface fabricated by laser texturing underwater." Tribology International **102**: 371-377.

Huang, S., L. Zhang, D. Li, W. Zhang and W. Zhu (2020). "Comparison of the microstructure and mechanical properties of FeCrNiBSi alloy fabricated by laser metal deposition in nitrogen and air." Surface and Coatings Technology **381**: 125123.

Hulka, I., D. Utu, V. A. Serban, P. Negrea, F. Lukáč and T. Chráska (2020). "Effect of Ti addition on microstructure and corrosion properties of laser cladded WC-Co/NiCrBSi(Ti) coatings." Applied Surface Science **504**: 144349.

Huth, S., N. Krasokha and W. Theisen (2009). "Development of wear and corrosion resistant cold-work tool steels produced by diffusion alloying." Wear **267**(1–4): 449-457.

Iveković, A., N. Omidvari, B. Vrancken, K. Lietaert, L. Thijs, K. Vanmeensel, J. Vleugels and J.-P. Kruth (2018). "Selective laser melting of tungsten and tungsten alloys." International Journal of Refractory Metals and Hard Materials **72**: 27-32.

Javdani, A., V. Pouyafar, A. Ameli and A. A. Volinsky (2016). "Blended powder semisolid forming of Al7075/Al2O3 composites: Investigation of microstructure and mechanical properties." Materials & Design **109**: 57-67.

Jiang, J., J. Yang, T. Zhang, J. Zou, Y. Wang, F. P. E. Dunne and T. B. Britton (2016). "Microstructurally sensitive crack nucleation around inclusions in powder metallurgy nickel-based superalloys." Acta Materialia **117**: 333-344.

Jiang, Y., Y. Cheng, X. Zhang, J. Yang, X. Yang and Z. Cheng (2020). "Simulation and experimental investigations on the effect of Marangoni convection on thermal field during laser cladding process." Optik **203**: 164044.

Jing, Z., H. Zhou, P. Zhang, C. Wang, C. Meng and D. Cong (2013). "Effect of thermal fatigue on the wear resistance of graphite cast iron with bionic units processed by laser cladding WC." Applied Surface Science **271**: 329-336.

Jothi, V., A. Y. Adesina, A. M. Kumar, N. Al-Aqeeli and J. S. N. Ram (2020). "Influence of an anodized layer on the adhesion and surface protective performance of organic coatings on AA2024 aerospace Al alloy." Progress in Organic Coatings **138**: 105396.

Kalin, M., A. Pogačnik, I. Etsion and B. Raeymaekers (2016). "Comparing surface topography parameters of rough surfaces obtained with spectral moments and deterministic methods." Tribology International **93, Part A**: 137-141.

Kang, S.-H., J.-J. Han, W.-T. Hwang, S.-M. Lee and H.-K. Kim (2019). "Failure analysis of die casting pins for an aluminum engine block." Engineering Failure Analysis **104**: 690-703.

Kattire, P., S. Paul, R. Singh and W. Yan (2015). "Experimental characterization of laser cladding of CPM 9V on H13 tool steel for die repair applications." Journal of Manufacturing Processes **20**: 492-499.

Kaur, N., C. Deng and O. A. Ojo (2020). "Effect of solute segregation on diffusion induced grain boundary migration studied by molecular dynamics simulations." Computational Materials Science **179**: 109685.

Kosec, B. (2008). "Failures of dies for die-casting of aluminium alloys." Metalurgija **47**.

Kou, S. (2003). Welding Metallurgy, John Wiley & Sons, Inc.

Kumar, D., S. Idapalapati, W. Wang and S. Narasimalu (2019). "Effect of Surface Mechanical Treatments on the Microstructure-Property-Performance of Engineering Alloys." Materials **12**(16): 2503.

La, P., Y. Ou, S. Han, Y. Wei, D. Zhu and J. Feng (2016). "Effect of Carbon Content on Morphology, Size and Phase of Submicron Tungsten Carbide Powders by Salt-assisted Combustion Synthesis." Rare Metal Materials and Engineering **45**(4): 853-857.

Lee, C. (2020). "Effect of strain rate on fatigue property of A356 aluminium casting alloys containing pre-existing micro-voids." International Journal of Fatigue **131**: 105368.

Lee, C., H. Park, J. Yoo, C. Lee, W. Woo and S. Park (2015). "Residual stress and crack initiation in laser clad composite layer with Co-based alloy and WC + NiCr." Applied Surface Science **345**: 286-294.

Lee, H., M. S. Park, M. T. Kim and C. Chu (2006). "Systematic finishing of dies and moulds." International Journal of Machine Tools & Manufacture - INT J MACH TOOL MANUF **46**: 1027-1034.

Lei, Y., R. Sun, Y. Tang and W. Niu (2015). "Microstructure and phase transformations in laser clad CrxSy/Ni coating on H13 steel." Optics and Lasers in Engineering **66**: 181-186.

Ley, N., S. S. Joshi, B. Zhang, Y.-H. Ho, N. B. Dahotre and M. L. Young (2018). "Laser coating of a CrMoTaWZr complex concentrated alloy onto a H13 tool steel die head." Surface and Coatings Technology **348**: 150-158.

Li, C.-L., Y. Yu, W.-J. Ye, S.-X. Hui, D.-G. Lee and Y.-T. Lee (2016). Effect of Boron Addition on Microstructure and Property of Low Cost Beta Titanium Alloy. TMS 2015 144th Annual Meeting & Exhibition, Cham, Springer International Publishing.

Li, H., G. Yuan, B. Guo and F. Yang (2020). "Study on the nucleation mechanism of hard particles in high boron and high carbon alloy by laser-induced arc welding." Optics & Laser Technology **121**: 105797.

Li, J., Y. Shi and X. Wu (2018). "Effect of initial hardness on the thermal fatigue behavior of AISI H13 steel by experimental sand numerical investigations." Fatigue & Fracture of Engineering Materials & Structures **41**.

Li, M., B. Han, L. Song and Q. He (2020). "Enhanced surface layers by laser cladding and ion sulfurization processing towards improved wear-resistance and self-lubrication performances." Applied Surface Science **503**: 144226.

Li, M., Q. Zhang, B. Han, L. Song, G. Cui, J. Yang and J. Li (2020). "Microstructure and property of Ni/WC/La2O3 coatings by ultrasonic vibration-assisted laser cladding treatment." Optics and Lasers in Engineering **125**: 105848.

Lin, B., K. Wang, F. Liu and Y. Zhou (2018). "An intrinsic correlation between driving force and energy barrier upon grain boundary migration." Journal of Materials Science & Technology **34**(8): 1359-1363.

Lin, Y.-C. and Y.-Y. Liu (2020). "Effects of Co and W on the microstructure and wear behavior of NiCrAlMoTiFeNbX equimolar multicomponent-clad layers." Wear **446-447**: 203186.

Lin, Y., H. Wen, Y. Li, B. Wen, W. Liu and E. J. Lavernia (2014). "Stress-Induced Grain Growth in an Ultra-Fine Grained Al Alloy." Metallurgical and Materials Transactions A **45**(6): 2673-2688.

Lin, Y., B. Xu, Y. Feng and E. J. Lavernia (2014). "Stress-induced grain growth during high-temperature deformation of nanostructured Al containing nanoscale oxide particles." Journal of Alloys and Compounds **596**: 79-85.

Lin, Y. C. and K. Y. Chang (2010). "Elucidating the microstructure and wear behavior of tungsten carbide multi-pass cladding on AISI 1050 steel." Journal of Materials Processing Technology **210**(2): 219-225.

Liu, B., A. Shi, Q. Su, G. Chen, W. Li, L. Zhang and B. Yang "Recovery of tungsten carbides to prepare the ultrafine WC-Co composite powder by two-step reduction process." Powder Technology.

Liu, B., B. Wang, X. Yang, X. Zhao, M. Qin and J. Gu (2019). "Thermal fatigue evaluation of AISI H13 steels surface modified by gas nitriding with pre- and post-shot peening." Applied Surface Science **483**: 45-51.

Liu, D., P. Hu and G. Min (2015). "Interfacial reaction in cast WC particulate reinforced titanium metal matrix composites coating produced by laser processing." Optics & Laser Technology **69**: 180-186.

Liu, G., S. Winwood, K. Rhodes and S. Birosca (2020). "The effects of grain size, dendritic structure and crystallographic orientation on fatigue crack propagation in IN713C nickel-based superalloy." International Journal of Plasticity **125**: 150-168.

Liu, H., X. Du, H. Guo, J. Liu, P. Chen, H. Yang and J. Hao (2021). "Finite element analysis of effects of dynamic preheating on thermal behavior of multi-track and multi-layer laser cladding." Optik **228**: 166194.

Lordan, E., J. Lazaro-Nebreda, Y. Zhang, K. Dou, P. Blake and Z. Fan (2020). "On the relationship between internal porosity and the tensile ductility of aluminium alloy die-castings." Materials Science and Engineering: A **778**: 139107.

Lourenço, J. M., S. D. Sun, K. Sharp, V. Luzin, A. N. Klein, C. H. Wang and M. Brandt (2016). "Fatigue and fracture behavior of laser clad repair of AerMet® 100 ultra-high strength steel." International Journal of Fatigue **85**: 18-30.

Lu, G. X., J. D. Liu, H. C. Qiao, G. L. Zhang, C. Y. Cui, Y. Z. Zhou, T. Jin, J. B. Zhao, X. F. Sun and Z. Q. Hu (2016). "Microscopic surface topography of a wrought superalloy processed by laser shock peening." Vacuum **130**: 25-33.

Lu, J. Z., J. Cao, H. F. Lu, L. Y. Zhang and K. Y. Luo (2019). "Wear properties and microstructural analyses of Fe-based coatings with various WC contents on H13 die steel by laser cladding." Surface and Coatings Technology **369**: 228-237.

Lu, L., T. Huang and M. Zhong (2012). "WC nano-particle surface injection via laser shock peening onto 5A06 aluminum alloy." Surface and Coatings Technology **206**(22): 4525-4530.

Lu, Y., K. Ripplinger, X. Huang, Y. Mao, D. Detwiler and A. A. Luo (2019). "A new fatigue life model for thermally-induced cracking in H13 steel dies for die casting." Journal of Materials Processing Technology **271**: 444-454.

M. Baricco, M. P., D. Baldissin, E. Bosco, L. Battezzati (2004). "Metastable phases and phase diagrams." Metallurgia Fisica: 11-12.

Ma, N.-n., J. Chen, Z.-r. Huang, Y.-j. Li, M. Liu, X.-j. Liu and Z.-m. Chen (2020). "Fabrication of amorphous silica coating on graphite substrate by laser cladding." Ceramics International.

Ma, Q., Y. Li, J. Wang and K. Liu (2015). "Investigation on cored-eutectic structure in Ni60/WC composite coatings fabricated by wide-band laser cladding." Journal of Alloys and Compounds **645**: 151-157.

Mahmoud, E. R. I., S. Z. Khan and M. Ejaz (2020). "Laser surface cladding of mild steel with 316L stainless steel for anti-corrosion applications." Materials Today: Proceedings.

Majumdar, J. D. and I. Manna (2003). "Laser processing of materials." Sadhana **28**(3-4): 495-562.

Markežič, R., I. Naglič, N. Mole and R. Šturm (2019). "Experimental and numerical analysis of failures on a die insert for high pressure die casting." Engineering Failure Analysis **95**: 171-180.

Matikainen, V., S. Rubio Peregrina, N. Ojala, H. Koivuluoto, J. Schubert, Š. Houdková and P. Vuoristo (2019). "Erosion wear performance of WC-10Co4Cr and Cr3C2-25NiCr coatings sprayed with high-velocity thermal spray processes." Surface and Coatings Technology **370**: 196-212.

Mazaheri Tehrani, H., R. Shoja-Razavi, M. Erfanmanesh, S. H. Hashemi and M. Barekat (2020). "Evaluation of the mechanical properties of WC-Ni composite coating on an AISI 321 steel substrate." Optics & Laser Technology **127**: 106138.

Medvedev, A. E., H. P. Ng, R. Lapovok, Y. Estrin, T. C. Lowe and V. N. Anumalasetty (2016). "Effect of bulk microstructure of commercially pure titanium on surface characteristics and fatigue properties after surface modification by sand blasting and acid-etching." Journal of the Mechanical Behavior of Biomedical Materials **57**: 55-68.

Mellouli, D., N. Haddar, A. Köster and H. F. Ayedi (2014). "Hardness effect on thermal fatigue damage of hot-working tool steel." Engineering Failure Analysis **45**: 85-95.

Messé, O. M. D. M., R. Muñoz-Moreno, T. Illston, S. Baker and H. J. Stone (2018). "Metastable carbides and their impact on recrystallisation in IN738LC processed by selective laser melting." Additive Manufacturing **22**: 394-404.

Messina, L., T. Schuler, M. Nastar, M.-C. Marinica and P. Olsson (2020). "Solute diffusion by self-interstitial defects and radiation-induced segregation in ferritic Fe-X (X=Cr, Cu, Mn, Ni, P, Si) dilute alloys." Acta Materialia.

Miao, J., T. M. Pollock and J. Wayne Jones (2009). "Crystallographic fatigue crack initiation in nickel-based superalloy René 88DT at elevated temperature." Acta Materialia **57**(20): 5964-5974.

Miller, A. E. and D. M. Maijer (2006). "Investigation of erosive-corrosive wear in the low pressure die casting of aluminum A356." Materials Science and Engineering: A **435-436**: 100-111.

Mitterer, C., F. Holler, F. Üstel and D. Heim (2000). "Application of hard coatings in aluminium die casting — soldering, erosion and thermal fatigue behaviour." Surface and Coatings Technology **125**(1): 233-239.

Mori, K.-i., T. Maeno, H. Yamada and H. Matsumoto (2015). "1-Shot hot stamping of ultra-high strength steel parts consisting of resistance heating, forming, shearing and die quenching." International Journal of Machine Tools and Manufacture **89**: 124-131.

Moskal, G., D. Niemiec, B. Chmiela, P. Kałamarz, T. Durejko, M. Ziętala and T. Czujko (2019). "Microstructural characterization of laser-cladded NiCrAlY coatings on Inconel 625 Ni-based superalloy and 316L stainless steel." Surface and Coatings Technology: 125317.

Natrella, M. (2012). Handbook of Statistical Methods, NIST/SEMATECH.

Natsui, S., H. Takai, T. Kumagai, T. Kikuchi and R. O. Suzuki (2014). "Stable mesh-free moving particle semi-implicit method for direct analysis of gas–liquid two-phase flow." Chemical Engineering Science **111**: 286-298.

Norhafzan, B. (2017). Laser Melting of High Thermal Conductivity Steel (HTCS) Surface, Trans Tech Publications.

Norhafzan, B., S. N. Aqida, E. Chikarakara and D. Brabazon (2016). "Surface modification of AISI H13 tool steel by laser cladding with NiTi powder." Applied Physics A **122**(4): 384.

Oh, S. and H. Ki (2017). "Prediction of hardness and deformation using a 3-D thermal analysis in laser hardening of AISI H13 tool steel." Applied Thermal Engineering **121**: 951-962.

Okawa, T. (2019). "A three-dimensional approach for simulating BWR core melt progression – A validation against CORA-BWR experimental series." Annals of Nuclear Energy **132**: 512-525.

Otsuki, A. (2015). Chapter 16 - Selective Dispersion and Characterization of Fine Particle Mixture in Concentrated Suspensions for Advanced Particle Processing. Handbook of Nanoceramic and Nanocomposite Coatings and Materials, Butterworth-Heinemann: 345-356.

Pang, X. and F. Zhou (2020). "Thermostability and weatherability of TiN/TiC-Ni/Mo solar absorption coating by spray method-laser cladding hybrid deposition." Optics and Lasers in Engineering **127**: 105983.

Patra Karmakar, D., M. Gopinath and A. K. Nath (2019). "Effect of tempering on laser remelted AISI H13 tool steel." Surface and Coatings Technology **361**: 136-149.

Paul, C. P., S. K. Mishra, P. Tiwari and L. M. Kukreja (2013). "Solid-Particle Erosion Behaviour of WC/Ni Composite Clad layers with Different Contents of WC Particles." Optics & Laser Technology **50**: 155-162.

Peng, Y., W. Zhang, T. Li, M. Zhang, B. Liu, Y. Liu, L. Wang and S. Hu (2020). "Effect of WC content on microstructures and mechanical properties of FeCoCrNi high-entropy alloy/WC composite coatings by plasma cladding." Surface and Coatings Technology **385**: 125326.

Phetlam, P. and V. Uthaisangsuk (2015). "Microstructure based flow stress modeling for quenched and tempered low alloy steel." Materials & Design **82**: 189-199.

Pineau, A., D. L. McDowell, E. P. Busso and S. D. Antolovich (2016). "Failure of metals II: Fatigue." Acta Materialia **107**: 484-507.

Qi, C., X. Zhan, Q. Gao, L. Liu, Y. Song and Y. Li (2019). "The influence of the pre-placed powder layers on the morphology, microscopic characteristics and microhardness of Ti-6Al-4V/WC MMC coatings during laser cladding." Optics & Laser Technology **119**: 105572.

Qu, H., H. Hou, P. Li, S. Li and X. Ren (2016). "The effect of thermal cycling in superplastic diffusion bonding of heterogeneous duplex stainless steel." Materials & Design **96**: 499-505.

Ratzker, B., A. Wagner, M. Sokol, S. Kalabukhov and N. Frage (2019). "Stress-enhanced dynamic grain growth during high-pressure spark plasma sintering of alumina." Acta Materialia **164**: 390-399.

Sadhu, A., A. Choudhary, S. Sarkar, A. M. Nair, P. Nayak, S. D. Pawar, G. Muvvala, S. K. Pal and A. K. Nath (2020). "A study on the influence of substrate pre-heating on mitigation of cracks in direct metal laser deposition of NiCrSiBC-60%WC ceramic coating on Inconel 718." Surface and Coatings Technology **389**: 125646.

Saha, A., D. K. Mondal, K. Biswas and J. Maity (2012). "Microstructural modifications and changes in mechanical properties during cyclic heat treatment of 0.16% carbon steel." Materials Science and Engineering: A **534**: 465-475.

Salem, M., S. Le Roux, G. Dour, P. Lamesle, K. Choquet and F. Rézaï-Aria (2019). "Effect of aluminizing and oxidation on the thermal fatigue damage of hot work tool steels for high pressure die casting applications." International Journal of Fatigue **119**: 126-138.

Schneider, M. F. (1998). Laser Cladding with Powder: Effect of Some Machining Parameters on Clad Properties.

Shabgard, M. R. and A. F. Najafabadi (2014). "The influence of dielectric media on nano-structured tungsten carbide (WC) powder synthesized by electro-discharge process." Advanced Powder Technology **25**(3): 937-945.

Shan, Q., Z. Li, Y. Jiang, R. Zhou and Y. Sui (2013). "Effect of Ni Addition on Microstructure of Matrix in Casting Tungsten Carbide Particle Reinforced Composite." Journal of Materials Science & Technology **29**(8): 720-724.

Shen, Z., C. Gu, H. Liu and X. Wang (2013). "An experimental study of overlapping laser shock micro-adjustment using a pulsed Nd:YAG laser." Optics & Laser Technology **54**(0): 110-119.

Shi, B., J. Wei and M. Pang (2015). "A modified cross-correlation algorithm for PIV image processing of particle-fluid two-phase flow." Flow Measurement and Instrumentation **45**: 105-117.

Shin, H. J., Y. T. Yoo, D. G. Ahn and K. Im (2007). "Laser surface hardening of S45C medium carbon steel using ND:YAG laser with a continuous wave." Journal of Materials Processing Technology **187–188**(0): 467-470.

Shuja, S. Z., B. S. Yilbas, H. Ali and C. Karatas (2016). "Laser pulse heating of steel mixing with WC particles in a irradiated region." Optics & Laser Technology **86**: 126-135.

Simsek, T., M. Izciler, S. Ozcan and A. Akkurt (2019). Laser cladding of hot work tool steel (H13) with TiC nanoparticles, Mersin University.

Singh, A. and E. B. Tadmor (2017). "Simulating the superheating of nanomaterials due to latent heat release in surface reconstruction." International Journal of Heat and Mass Transfer **107**: 792-804.

Sınmazçelik, T., S. Fidan and S. Ürgün (2020). "Effects of 3D printed surface texture on erosive wear." Tribology International **144**: 106110.

Skumavc, A., J. Tušek, A. Nagode and D. Klobčar (2016). "Thermal fatigue study of tungsten alloy WNi28Fe15 cladded on AISI H13 hot work tool steel." Surface and Coatings Technology **285**: 304-311.

Srivastava, A., V. Joshi and R. Shivpuri (2004). "Computer modeling and prediction of thermal fatigue cracking in die-casting tooling." Wear **256**(1): 38-43.

Stachowiak, G. B. and G. W. Stachowiak (2010). "Tribological characteristics of WC-based claddings using a ball-cratering method." International Journal of Refractory Metals and Hard Materials **28**(1): 95-105.

Stinville, J. C., E. Martin, M. Karadge, S. Ismonov, M. Soare, T. Hanlon, S. Sundaram, M. P. Echlin, P. G. Callahan, W. C. Lenthe, V. M. Miller, J. Miao, A. E. Wessman, R. Finlay, A. Loghin, J. Marte and T. M. Pollock (2018). "Fatigue deformation in a polycrystalline nickel base superalloy at intermediate and high temperature: Competing failure modes." Acta Materialia **152**: 16-33.

Sun, J., Y.-s. Xu, X.-m. Wang and Z.-s. Zou (2013). "Anti-Thermal-Fatigue Property of 8407 Steel With Surface Aluminization and Oxidation Treatment." Journal of Iron and Steel Research, International **20**(1): 53-57.

Sundaraselvan, S., N. Senthilkumar, T. Tamizharasan and A. N. Sait (2020). "Surface modification of AZ61 Magnesium Alloy with Nano TiO2/Al2O3 using Laser Cladding Technique." Materials Today: Proceedings **21**: 717-721.

Tamanna, N., R. Crouch and S. Naher (2019). "Progress in numerical simulation of the laser cladding process." Optics and Lasers in Engineering **122**: 151-163.

Telasang, G., J. Dutta Majumdar, G. Padmanabham and I. Manna (2014). "Structure–property correlation in laser surface treated AISI H13 tool steel for improved mechanical properties." Materials Science and Engineering: A **599**: 255-267.

Telasang, G., J. Dutta Majumdar, G. Padmanabham, M. Tak and I. Manna (2014). "Effect of laser parameters on microstructure and hardness of laser clad and tempered AISI H13 tool steel." Surface and Coatings Technology **258**: 1108-1118.

Telasang, G., J. Dutta Majumdar, N. Wasekar, G. Padmanabham and I. Manna (2015). "Microstructure and Mechanical Properties of Laser Clad and Post-cladding Tempered AISI H13 Tool Steel." Metallurgical and Materials Transactions A **46**(5): 2309-2321.

Timoshenko, S. (1983). History of Strength of Materials: With a Brief Account of the History of Theory of Elasticity and Theory of Structures, Dover Publications.

Tolcha, M. A., H. Altenbach and G. S. Tibba (2020). "Modeling creep-fatigue interaction damage and H13 tool steel material response for rolling die under hot milling." Engineering Fracture Mechanics **223**: 106770.

Tomala, A., S. Hernandez, M. Rodriguez Ripoll, E. Badisch and B. Prakash (2014). "Tribological performance of some solid lubricants for hot forming through laboratory simulative tests." Tribology International **74**: 164-173.

Usha Rani, P. H., B. M. Rajaprakash, N. Mohan and M. Akshay Prasad (2019). "Study on thermal and erosive wear behaviour of hard powders filled glass-epoxy composite." Materials Today: Proceedings.

Vázquez-Fernández, N. I., T. Nyyssönen, M. Isakov, M. Hokka and V. T. Kuokkala (2019). "Uncoupling the effects of strain rate and adiabatic heating on strain induced martensitic phase transformations in a metastable austenitic steel." Acta Materialia **176**: 134-144.

Venter, A. M., V. Luzin, D. Marais, N. Sacks, E. N. Ogunmuyiwa and P. H. Shipway (2020). "Interdependence of slurry erosion wear performance and residual stress in WC-12wt%Co and WC-10wt%VC-12wt%Co HVOF coatings." International Journal of Refractory Metals and Hard Materials **87**: 105101.

Viana, R., M. S. F. de Lima, W. F. Sales, W. M. da Silva Jr and Á. R. Machado (2015). "Laser texturing of substrate of coated tools — Performance during machining and in adhesion tests." Surface and Coatings Technology **276**: 485-501.

Vinarcik, E. J. (2002). High Integrity Die Casting Processes, John Wiley & Sons.

Wang, D., Q. Hu, Y. Zheng, Y. Xie and X. Zeng (2016). "Study on deposition rate and laser energy efficiency of Laser-Induction Hybrid Cladding." Optics & Laser Technology **77**: 16-22.

Wang, G., J. Zhang, R. Shu and S. Yang (2019). "High temperature wear resistance and thermal fatigue behavior of Stellite-6/WC coatings produced by laser cladding with Co-coated WC powder." International Journal of Refractory Metals and Hard Materials **81**: 63-70.

Wang, L., W. G. Jiang and L. H. Lou (2015). "The deformation and the recrystallization initiation in the dendrite core and interdendritic regions of a directionally solidified nickel-based superalloy." Journal of Alloys and Compounds **629**: 247-254.

Wang, Y., A. Charbal, F. Hild, S. Roux and L. Vincent (2019). "Crack initiation and propagation under thermal fatigue of austenitic stainless steel." International Journal of Fatigue **124**: 149-166.

Wang, Y., Z. Liang, J. Zhang, Z. Ning and H. Jin (2016). "Microstructure and Antiwear Property of Laser Cladding Ni–Co Duplex Coating on Copper." Materials **9**(8): 634.

Wang, Z., C. Wang, Y.-L. Zhao, Y.-C. Hsu, C.-L. Li, J.-J. Kai, C.-T. Liu and C.-H. Hsueh (2020). "High hardness and fatigue resistance of CoCrFeMnNi high entropy alloy films with ultrahigh-density nanotwins." International Journal of Plasticity: 102726.

Wawrzyniak, J., J. Karczewski, P. Kupracz, K. Grochowska, K. Załęski, O. Pshyk, E. Coy, M. Bartmański, M. Szkodo and K. Siuzdak (2020). "Laser-assisted modification of titanium dioxide nanotubes in a tilted mode as surface modification and patterning strategy." Applied Surface Science **508**: 145143.

Wen, J.-b., C.-Y. Zhou, X. Li, X.-M. Pan, L. Chang, G.-D. Zhang, F. Xue and Y.-F. Zhao (2019). "Effect of temperature range on thermal-mechanical fatigue properties of P92 steel and fatigue life prediction with a new cyclic softening model." International Journal of Fatigue **129**: 105226.

Weng, F., H. Yu, C. Chen, J. Liu, L. Zhao and J. Dai (2016). "Microstructure and property of composite coatings on titanium alloy deposited by laser cladding with Co42+TiN mixed powders." Journal of Alloys and Compounds **686**: 74-81.

Weng, Z., A. Wang, X. Wu, Y. Wang and Z. Yang (2016). "Wear resistance of diode laser-clad Ni/WC composite coatings at different temperatures." Surface and Coatings Technology **304**: 283-292.

Xu, Y., H. Liu, R. Bao and X. Zhang (2018). "Residual stress evaluation in welded large thin-walled structures based on eigenstrain analysis and small sample residual stress measurement." Thin-Walled Structures **131**: 782-791.

Yan, H., K. Liu, P. Zhang, J. Zhao, Y. Qin, Q. Lu and Z. Yu (2020). "Fabrication and tribological behaviors of Ti3SiC2/Ti5Si3/TiC/Ni-based composite coatings by laser cladding for self-lubricating applications." Optics & Laser Technology **126**: 106077.

Yang, J., X. Miao, X. Wang, H. Chen and F. Yang (2016). "Microstructure, magnetic properties and empirical electron theory calculations of laser cladding FeNiCr/60%WC composite coatings with Mo additions." International Journal of Refractory Metals and Hard Materials **54**: 216-222.

Yang, J., F. Wu, B. Bai, G. Wang, L. Yang, S. Zhou and J. Lei (2020). "Effect of Cr additions on the microstructure and corrosion resistance of Diode laser clad CuAl10 coating." Surface and Coatings Technology **381**: 125215.

Yang, X., J. Li and P. Wang (2020). "Grain boundary migration in nanocrystalline Ni under constant shear strains and its mechanism." Computational Materials Science **176**: 109530.

Yang, Y., A. Wang, D. Xiong, Z. Wang, D. Zhou, S. Li and H. Zhang (2020). "Effect of Cr content on microstructure and oxidation resistance of laser-clad Cu-Ni-Fe-Mo-xCr alloy coating." Surface and Coatings Technology **384**: 125316.

Yao, J., J. Zhang, G. Wu, L. Wang, Q. Zhang and R. Liu (2018). "Microstructure and wear resistance of laser cladded composite coatings prepared from pre-alloyed WC-NiCrMo powder with different laser spots." Optics & Laser Technology **101**: 520-530.

Yilbas, B. S., S. S. Akhtar, C. Karatas and K. Boran (2016). "Laser treatment of dual matrix cast iron with presence of WC particles at the surface: Influence of self-annealing on stress fields." Optics & Laser Technology **76**: 6-18.

Yuan, W.-X. and Z. J. Li (2012). "Effects of PVA organic binder on electric properties of CaCu3Ti4O12 ceramics." Journal of Physics and Chemistry of Solids **73**(4): 599-603.

Zabler, S., A. Ershov, A. Rack, F. Garcia-Moreno, T. Baumbach and J. Banhart (2013). "Particle and liquid motion in semi-solid aluminium alloys: A quantitative in situ microradioscopy study." Acta Materialia **61**(4): 1244-1253.

Zhang, L., G. Yu, S. Li, X. He, X. Xie, C. Xia, W. Ning and C. Zheng (2019). "The effect of laser surface melting on grain refinement of phase separated Cu-Cr alloy." Optics & Laser Technology **119**: 105577.

Zhang, Y., J. Zheng, Y. Xia, H. Shou, W. Tan, W. Han and Q. Liu (2020). "Porosity quantification for ductility prediction in high pressure die casting AM60 alloy using 3D X-ray tomography." Materials Science and Engineering: A **772**: 138781.

Zhang, Z., F. Kong and R. Kovacevic (2020). "Laser hot-wire cladding of Co-Cr-W metal cored wire." Optics and Lasers in Engineering **128**: 105998.

Zhang, Z. and R. Kovacevic (2019). "Laser cladding of iron-based erosion resistant metal matrix composites." Journal of Manufacturing Processes **38**: 63-75.

Zhou, J., H. Shen, Y. Pan and X. Ding (2016). "Experimental study on laser microstructures using long pulse." Optics and Lasers in Engineering **78**: 113-120.

Zhou, S., X. Dai and H. Zheng (2012). "Microstructure and wear resistance of Fe-based WC coating by multi-track overlapping laser induction hybrid rapid cladding." Optics & Laser Technology **44**(1): 190-197.

Zhou, S., J. Lei, X. Dai, J. Guo, Z. Gu and H. Pan (2016). "A comparative study of the structure and wear resistance of NiCrBSi/50 wt.% WC composite coatings by laser cladding and laser induction hybrid cladding." International Journal of Refractory Metals and Hard Materials **60**: 17-27.

Zhou, S., Y. Xu, B. Liao, Y. Sun, X. Dai, J. Yang and Z. Li (2018). "Effect of laser remelting on microstructure and properties of WC reinforced Fe-based amorphous composite coatings by laser cladding." Optics & Laser Technology **103**: 8-16.

Zinoviev, A., O. Zinovieva, V. Ploshikhin, V. Romanova and R. Balokhonov (2016). "Evolution of grain structure during laser additive manufacturing. Simulation by a cellular automata method." Materials & Design **106**: 321-329.

Zou, Y., B. Ma, H. Cui, F. Lu and P. Xu (2020). "Microstructure, wear, and oxidation resistance of nanostructured carbide-strengthened cobalt-based composite coatings on Invar alloys by laser cladding." Surface and Coatings Technology **381**: 125188.

Zulhishamuddin, A. R., S. N. Aqida and M. Mohd Rashidi (2018). "A comparative study on wear behaviour of Cr/Mo surface modified grey cast iron." Optics & Laser Technology **104**: 164-169.