

**LASER SURFACE MODIFICATION OF TOOL
STEELS FOR ENHANCING SURFACE
PROPERTIES**

by

LEONG KA IP

Master of Science in Electromechanical Engineering

2006



**Faculty of Science and Technology
University of Macau**

TABLE OF CONTENTS

| | |
|---|-----|
| LIST OF FIGURES..... | v |
| LIST OF TABLES..... | xi |
| LIST OF PUBLICATIONS..... | xiv |
| ACKNOWLEDGMENTS..... | xv |
| ABSTRACT..... | xvi |
| CHAPTER 1: INTRODUCTION..... | p1 |
| 1.1 Tool steels..... | p1 |
| 1.2 Corrosion of metallic materials..... | p2 |
| 1.3 Corrosion prevention and control..... | p2 |
| 1.4 Surface modification..... | p3 |
| 1.4.1 Conventional surface modification..... | p4 |
| 1.4.2 Laser surface modification..... | p5 |
| 1.4.3 Types of laser use in laser surface modification..... | p6 |
| 1.5 Objectives..... | p7 |
| CHAPTER 2: LITERATURE REVIEW..... | p9 |
| 2.1 Classification and applications of tool steels..... | p9 |
| 2.1.1 High speed steels..... | p10 |
| 2.1.2 Plastic mold steels..... | p11 |
| 2.1.3 Cold and hot work steels..... | p12 |
| 2.1.4 Shock resistant steels..... | p14 |
| 2.1.5 Special purpose steels..... | p15 |
| 2.2 Conventional heat treatment of tool steels..... | p15 |
| 2.2.1 Tool steels in as-received condition..... | p15 |
| 2.2.2 Heat treatment process..... | p15 |
| 2.2.2.1 Austenitisation..... | p16 |
| 2.2.2.2 Quenching..... | p16 |
| 2.2.2.3 Tempering..... | p17 |
| 2.2.3 Influence of alloying element..... | p18 |

| | | |
|---|---|------------|
| 2.3 | Laser surface modification..... | p20 |
| 2.3.1 | Laser transformation hardening (LTH)..... | p23 |
| 2.3.2 | Laser surface melting (LSM) | p26 |
| 2.3.3 | Laser surface alloying (LSA)..... | p29 |
| 2.3.4 | Laser cladding (LC)..... | p29 |
| 2.3.5 | Nd:YAG laser system | p30 |
| 2.3.6 | Methods of beam spreading..... | p31 |
| 2.3.7 | Heat balance equation..... | p32 |
| 2.3.8 | Mathematical model of heat transfer for LTH..... | p34 |
| 2.3.9 | Mathematical model of heat transfer for LSM..... | p35 |
| 2.3.10 | Absorption of laser radiation..... | p39 |
| 2.4 | Rapid solidification and microstructure..... | p43 |
| 2.5 | Corrosion and wear..... | p45 |
| 2.5.1 | Wear of metallic materials..... | p46 |
| 2.5.2 | Corrosion of metallic material..... | p46 |
| 2.5.2.1 | Electrochemical reactions..... | p47 |
| 2.5.2.2 | Forms of corrosions..... | p48 |
| 2.5.2.3 | Corrosion potential..... | p51 |
| 2.5.2.4 | Passivity..... | p52 |
| 2.5.2.5 | Factors affecting corrosion..... | p52 |
| 2.5.2.6 | Determination of corrosion characteristics..... | p52 |
| 2.6 | Improving surface properties by laser surface modification..... | p55 |
| CHAPTER 3: EXPERIMENTAL DETAILS..... | | p59 |
| 3.1 | Materials and specimens preparation..... | p59 |
| 3.2 | Laser surface modification..... | p60 |
| 3.3 | Metallographic and microstructure examination..... | p62 |
| 3.4 | Microhardness test..... | p63 |
| 3.5 | Corrosion tests..... | p64 |
| 3.6 | Summary of tests..... | p68 |
| CHAPTER 4: RESULTS AND DISCUSSION I : LASER SURFACE MODIFICATION OF PLASTIC MOLD STEELS..... | | p70 |

| | |
|--|-------------|
| 4.1. Microstructure and metallographic analysis..... | p70 |
| 4.1.1 Laser-treated P21 and P20 | p70 |
| 4.1.2 Laser-treated 440C and 420 | p79 |
| 4.2 Hardness profile..... | p88 |
| 4.3 Corrosion behaviour..... | p89 |
| 4.3.1 Laser-treated P21 and P20 | p90 |
| 4.3.2 Laser-treated 440C and 420 | p94 |
| CHAPTER 5: RESULTS AND DISCUSSION II: LASER SURFACE MODIFICATION OF HIGH SPEED STEELS..... | p99 |
| 5.1. Microstructure and metallographic analysis..... | p99 |
| 5.1.1 Laser-treated M2 | p100 |
| 5.1.2 Laser-treated ASP23 and ASP30 | p108 |
| 5.2 Hardness profile..... | p115 |
| 5.3 Corrosion behaviour of laser-treated HSS..... | p118 |
| CHAPTER 6: RESULTS AND DISCUSSION III : LASER SURFACE MODIFICATION OF HOT/COLD WORK STEELS..... | p122 |
| 6.1. Microstructure and metallographic analysis..... | p122 |
| 6.1.1 Laser-treated H13 | p124 |
| 6.1.2 Laser-treated O1 | p130 |
| 6.1.3 Laser-treated D6 | p136 |
| 6.2 Hardness profile..... | p141 |
| 6.2.1 Laser-treated H13..... | p141 |
| 6.2.2 Laser-treated O1 | p142 |
| 6.2.3 Laser-treated D6 | p142 |
| 6.3 Corrosion behaviour..... | p145 |
| 6.3.1 Laser-treated H13 | p145 |
| 6.3.2 Laser-treated O1 | p147 |
| 6.3.3 Laser-treated D6 | p148 |
| CHAPTER 7: OVERALL DISCUSSION..... | p150 |
| 7.1 Summary of results..... | p150 |
| 7.2 Laser treatment for enhancing surface hardness..... | p153 |

7.3 Laser treatment for enhancing corrosion resistance.....p161

7.4 Correlation between corrosion resistance / hardness and the alloy content by multiple regression.....p167

CHAPTER 8: CONCLUSIONS.....p174

8.1 Laser surface modification of plastic mold steels (P20, P21, 420 and 440C).....p174

8.2 Laser surface modification of high speed steels (M2, ASP23 and ASP30).....p176

8.3 Laser surface modification of hot/cold work steels (H13, O1, and D6).....p177

8.4 Multiple regression for the corrosion resistance and alloy content in various treated conditions.....p178

8.5 Recommendation of further work.....p178

REFERENCES.....p180