A NEW NUMERICAL APPROACH FOR HEAT CONDUCTION AND PHASE TRANSFORMATION ANALYSIS OF LASER SURFACE HARDENING

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Thesis Submitted in Fulfillment of the Requirement for the Degree of Master of Science in the Faculty of Science and Technology University Malaysia Terengganu

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DEDICATION

This thesis is dedicated to my mother, Hj. Aida Baharudin, my late father, H. Sarwo Sugeng, and my brothers, Ari Aldi and Johan Palavi. They always give me so many loves, happiness, and support in entire my life. They are my motivation to finish this research and in everything I do in this life.

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A large number of machine components which based on steel or metal require a combination of properties of high surface hardness along with good toughness and wear resistance due to severe conditions of high-stressed located on their surface, which is usually not possible in a conventional heat treatment method. Laser surface hardening as one of the heat treatment methods has become the most appropriately method to increase the wear resistance, toughness and hardness of the material's surface without affecting the bulk material. However, the whole process of laser surface hardening is very complex due to involving many parameters and occurs on the microscope scale. Moreover, there are many conditions which have to be considered carefully to ensure the hardening process running as expected.

Knowledge about relations between the input and output parameters become important in order to determine the best combination of processing

parameters which producing desired outcomes. Simulation study can be used to reduce the range of conditions over which experimental testing is required. In this case, experiments which would normally be time consuming and expensive, can be performed and repeated easily, as well as analyzed thoroughly. A new 2-D numerical model is developed by using implicit scheme of finite difference method, namely Crank-Nicolson method, for simulating heat conduction inside a steel slab during laser surface hardening process. The results which obtained by this numerical solution compared to the analytical solution and showing a better suitability.

Several experiments were carried out using this numerical model in order to investigate influences of processing parameters to temperature profiles and hardened zone inside the work material. It was found that the heat is conducted more effectively in the axial direction than in the radial direction. In addition, the processing parameters of laser surface hardening have different effects to the temperature profiles and hardened zone inside the steel slab, which will be explained more detail in this thesis. Finally, the numerical model was integrated with a graphical user interface (GUI) to provide a user-friendly environment for performing virtual experiments with various combinations of the operational parameters.

Abstrak tesis yang dikemukakan kepada Senat Universiti Malaysia Terengganu sebagai memenuhi keperluan untuk ijazah Master Sains

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Sejumlah besar komponen mesin yang berbahan asas logam memerlukan kombinasi sifat berupa kekerasan permukaan yang tinggi disertai dengan kekuatan dan ketahanan karat yang baik kerana tingginya *stress* pada permukaannya, yang biasanya tidak mungkin diperolehi dengan kaedah perlakuan haba biasa. *Laser Surface Hardening* sebagai salah satu kaedah perlakuan haba telah menjadi metode yang paling sesuai untuk meningkatkan ketahanan karat, kekuatan, dan kekerasan permukaan bahan tanpa mempengaruhi sebahagian besar bahan itu sendiri. Akan tetapi, keseluruhan proses *Laser Surface Hardening* sangatlah kompleks kerana melibatkan banyak parameter dan terjadi di dalam skala mikroskopik. Selain itu, terdapat banyak kondisi yang harus diperhatikan secara hati-hati untuk memastikan proses pengerasan berjalan seperti yang diharapkan.

Pengetahuan mengenai hubungan antara parameter *input* dan *output* menjadi penting dalam rangka menentukan kombinasi parameter pemprosesan terbaik yang menghasilkan keputusan yang dikehendaki. Pengajian permodelan boleh digunakan untuk mengurangkan pelbagai keadaan di mana pengujian eksperimental diperlukan. Dalam hal ini, percubaan yang biasanya akan memakan masa dan mahal kosnya, boleh dilakukan dan diulang dengan mudah, serta dianalisis secara menyeluruh. Sebuah model berangka 2-D baru telah dibangunkan dengan menggunakan skim tersirat kaedah beza hingga, iaitu kaedah Crank-Nicolson, untuk mensimulasikan konduksi haba di dalam plat baja semasa proses *laser surface hardening*. Keputusan yang diperolehi dengan penyelesaian berangka ini dibandingkan dengan penyelesaian analitik dan menunjukkan keputusan yang lebih baik.

Beberapa eksperimen dilakukan dengan menggunakan model berangka ini dalam rangka menyelidik pengaruh dari parameter pemprosesan terhadap profil suhu dan daerah yang mengeras di dalam bahan. Hal ini diketahui bahawa haba dikonduksikan lebih berkesan dalam arah axial berbanding arah radial. Selain itu, parameter proses *laser surface hardening* memiliki pengaruh yang berbeza terhadap profil suhu dan daerah yang mengeras di dalam plat baja, yang akan dijelaskan lebih mendalam dalam tesis ini. Akhirnya, model berangka ini terintegrasi dengan *graphical user interface* (GUI) untuk menyediakan persekitaran yang *user- friendly* untuk melakukan eksperimen maya dengan pelbagai kombinasi parameter pemprosesan