UNIVERSITI PUTRA MALAYSIA

GEOMETRICAL AND DIMENSIONAL DEFECT EVALUATION OF COLD FORGED AA6061 PROPELLER BLADE

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

GEOMETRICAL AND DIMENSIONAL DEFECT EVALUATION OF COLD FORGED AA6061 PROPELLER BLA DE

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March 2013

Chair: Mohd Sapuan Salit, PhD, PEng

Faculty: Engineering

Accuracy is a key issue in cold forging process. Component defect is one of the major problems in cold forging because the process depends on many factors including complexity of the component. Defect not only affects the performance of the component but may also harm the assembly. The problem of defect becomes more critical as the complexity of the component increases, but the size and complexity of the part limit the effective assessment of the defect. This project aims to investigate the geometrical and dimensional defects that occur in Autonomous Underwater Vehicle propeller blades produced using the cold forging process. Typically the manufacturing of the blade can be divided into five stages namely, blanking, forming, trimming, heading and twisting. The defect was evaluated based on the three main criteria of the blade. First, the overall geometrical and dimensional accuracy of the blade was measured. In this study, the profile of the forged blade was considered as the final part, whereas the profile obtained from the punch was considered as the targeted profile. The profile was captured using a commercial focus variation based 3D surface measurement system, the *Infinite Alicona System*. The constructed 3D profile was then compared to a nominal model. Next, the filling ability of the pin head during the cold embossing or heading process was investigated,

because an imperfect or defective pin head may affect the final assembly of the blade. In this work, the effects of design and process parameters, including punch diameter and distance to edge on the formation of defect, were studied using the commercial 2D finite element analysis software DEFORM-2D. The defect can be estimated based on the incomplete filling of the region and the amount of bulging based on the captured images of the simulation result. In addition, the defect was predicted by investigating the design parameters and its effect on the material flow pattern. Comparison between the simulation result and the fabricated pin head show a geometrically similar pattern. Finally, the twist springback was measured. In this study, defect was considered based on profile deviation, which was obtained from the 3D surface measurement technique. An algorithm was developed to measure the deviation. The result showed that the thickness error depended on the deformation ratio whereas the twist angle accuracy relied on the amount of twist and thickness of the blade. In the other case, the simulation results indicated that the most significant parameter for the filling ability and amount of bulging was the distance to edge, whereas the punch taper was not relevant for cases of edge embossing. In the case of twist springback, the results implied that the twist springback increased as the twist angle increased. The highest springback was found to be at 16.11% for section E, while the lowest is 2.58% for section A. Similarly, the twist springback increased with the increase in deformation ratio. The coordinate measurement machine was used to validate the result. This study will contribute to the development of effective evaluation method in the non-contact measurement of geometrical and dimensional defect of component with complex profile such as the propeller blade.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENILAIAN KECACATAN GEOMETRIKAL DAN DIMENSI BILAH PENUJAH AA6061 YANG DIHASILKAN SECARA TEMPAAN SEJUK

Oleh

AHMAD BAHARUDDIN ABDULLAH

Mac 2013

Pengerusi: Mohd Sapuan Salit PhD, PEng

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Kejituan merupakan kunci utama dalam proses tempaan sejuk. Kecacatan komponen adalah merupakan salah satu masalah utama dalam tempaan sejuk disebabkana proses ini bergantung kepada banyak faktor termasuklah kerumitan komponen. Kecacatan bukan sahaja memberi kesan kepada prestasi komponen, tetapi ianya juga akan merosakkan pemasangan. Masalah kecacatan akan menjadi lebih kritikal selaras dengan peningkatan kerumitan komponen tersebut, ini kerana, saiz dan kerumitan komponen telah menghadkan keberkesanan penilaian kecacatan tersebut. Projek ini bertujuan untuk menyiasat kecacatan geometrikal dan dimensi yang wujud dalam bilah-bilah penujah Kenderaan Bawah-Air Autonomous yang telah dihasilkan menggunakan proses tempaan sejuk. Secara dasarnya, pembuatan bilah boleh dibahagikan kepada lima peringkat, yang dinamakan sebagai pengosongan, pembentukan, perapian, penghasilan kepala dan piuhan. Kecacatan dinilai berdasarkan tiga kriteria dan sifat. Yang pertama ialah pengukuran kejituan keseluruhan kecacatan geometrikal dan dimensi bilah. Dalam kajian ini, profil bilah yang dihasilkan melalui tempaan mewakili komponen akhir yang terhasil, manakala profil yang terhasil daripada penghentam dikira sebagai profil yang diharapkan pada bilah. Profil-profil ini akan terhasil dengan menggunakan sistem pengukuran permukaan 3D komersial yang

dibangunkan berdasarkan variasi fokus yang dinamakan, *Infinite Alicona System*. Profil 3D yang dihasilkan kemudiannya akan dibandingkan dengan model nominal bilah. Seterusnya kriteria yang kedua dan paling utama ialah kajian keboleh-isian kepala pin yang dihasilkan semasa proses penimbulan sejuk. Ini kerana ketidak sempurnaan atau kepala pin yang cacat akan memberi kesan kepada pemasangan akhir bilah. Dalam kajian ini, kesan parameter-parameter rekabentuk dan proses termasuklah diameter penghentam dan jarak ke bucu kepada pembentukan kecacatan telah dikaji dengan menggunakan perisian komersial analisis unsur terhingga DEFORM-2D. Kecacatan telah dianggarkan berdasarkan ketidak-sempurnaan pengisian kawasan dan bonjolan daripada imej yang diambil daripada keputusan simulasi. Selain itu, kecacatan juga diramal dengan menyiasat parameter rekabentuk dan kesannya kepada bentuk aliran bahan yang menjurus kepada kemunculan cacat. Akhir sekali, bidas-balik piuhan telah diukur. Dalam kajian ini, kecacatan dipertimbangkan berdasarkan sisihan profil yang terhasil daripada teknik pengukuran permukaan 3D. Algoritma dibina untuk mengukur sisihan. Keputusan daripada kajian yang telah dijalankan menunjukkan ralat ketebalan bergantung kepada nisbah perubahan-bentuk, manakala kejituan sudut piuhan bergantung kepada amaun piuhan dan ketebalan bilah. Dalam kes lain, keputusan simulasi menunjukkan yang parameter yang paling signifikan kepada keboleh-pengisian dan amaun bonjol adalah jarak ke bucu, malahan penghentam dengan serongan pun tidak relevan kepada kes proses penimbulan bucu. Perbandingan antara keputusan simulasi dan hasil tempaan sejuk menujukkan bentuk yang secara geometrinya sama. Manakala dalam kajian bidasan-balik piuhan menunjukkan peningkatan bidas-balik selaras dengan peningkatan sudut piuhan. Piuhan paling tinggi adalah 16.11% bagi seksyen E, manakala yang paling rendah adalah 2.58% untuk seksyen A. Begitu juga, bidasan-balik piuhan bertambah dengan pengingkatan nisbah perubahan-bentuk. Dalam kajian ini, mesin pengukuran koordinat digunakan untuk mengesahkan keputusan yang

diperolehi. Kajian ini menyumbang kepada kaedah penilaian yang lebih efektif dalam mengukur tanpa-sentuh kecacatan geometrikal dan dimensi komponen berprofil rumit seperti bilah penujah.

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APPROVAL

I certify that an Examination Committee met on 12 March 2013 to conduct the final examination of Ahmad Baharuddin Abdullah on his Doctor of Philosophy thesis entitled "Geometrical and Dimensional Defect Evaluation of Cold Forged AA6061 Propeller Blade" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or other institution.

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AHMAD BAHARUDDIN ABDULLAH

Date: 12 March 2013

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