UNIVERSITI PUTRA MALAYSIA

FINITE ELEMENT ANALYSIS AND OPTIMIZATION OF CLOSED DIE FORGING PROCESS FOR ALUMINIUM METAL MATRIX COMPOSITES

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By

MOHAMED A. ABDULMAWLLA

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

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DEDICATION

To whom their true love and support were behind my success

my mother, wife, daughter, son, brothers, sisters and to the

soul of my father may Allah bless him and grant him peace.

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

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Chair: **Professor Shamsuddin bin Sulaiman, PhD**

Faculty: **Institute of Advanced Technology**

The demand for lighter and stiffer products has been increasing in the last few years especially in automobile and aerospace manufacturing. The closed die forging process of aluminium metal matrix composite (Al-MMC) material is presented as possible solution, because it produces parts with good mechanical properties and lighter weight. The computational modelling of closed die forging process, using finite element method and optimization techniques, makes the design optimization faster and more efficient, decreasing the use of conventional “trial and error” methods.

In this work, a commercial finite element software, ANSYS has been used to model cold closed die forging process. The model is developed using ANSYS Parametric Design Language (APDL) to simulate a single stage axi-symmetry closed die forging process for H-cross sectional shape. Axisymmetric forgings with rib-web represent about 50% of the total forging output. So that the H-cross sectional shape used in this study has a wide applications.

Simple compression test was carried out for aluminium alloy 6061 in order to determine its flow curve. Closed die forging experiment was conducted using aluminium alloy 6061 and then the experiment was simulated in order to verify the model for large deformation. The simulation results showed similar output with the experimental one. As a result, the model can be confidently used to simulate closed die forging for particulate reinforced Al-MMC.

The Al-MMC material considered is AlMgSi matrix with 15%vol SiC particles, its flow curve and fractural strain are obtained from the literature. ANSYS Optimizer is used to obtain the maximum height that the material can flow in the rib by changing the design variables (DV) and the state variables (SV). Generally, design variables are geometrical parameters such as rib height to width ratio, web height to rib height ratio, fillet radii, draft angle and billet radius. State variables (SV) are some parameters that depend on the design variables such as the equivalent strain which must be below the fracture strain of the aluminium metal composite (AMC) material, and an acceptable contact gap (within the allowable tolerance range).

The objective of this work is to achieve through simulation, the optimal die shape and billet diameter in consideration of complete die filling and the influence of metal flow deformation of Aluminium Metal Matrix Composite in a single stage closed die forging process. A commercially available finite element package (ANSYS) was used to investigate the effect of different die shapes and billet diameters on the closed die forging deformation. Optimization method called “Sub-Problem Approximation Method” was used to find out the optimal design set.

The maximum rib height obtained in the single stage cold closed die forging of H-cross sectional shape disc made of AlMgSi matrix with 15%vol SiC particles is 0.185 of the disc radius. Trying to get higher rib height lead to higher strain and cracks will occur in the fillet region. The rib width and the web height are 0.218 and 0.3 of the disc radius simultaneously. Optimal billet height is 0.99 of the disc radius. The billet radius is a function of the die cavity volume and the billet height. The technique used in this work can be used for newly developed materials to investigate its forgeability for more complicated shapes in closed die forging process.

Abstrak projek yang dikemukakan kepada Senat universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

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Permintaan terhadap produk yang ringan dan kaku semakin meningkat dalam beberapa tahun terakhir terutama sekali dalam bidang pembuatan kereta dan aeroangkasa. Proses penempaan acuan tertutup bagi bahan logam aluminium matrik komposit (Al-MMC) dibentangkan sebagai penyelesaian mungkin, kerana menghasilkan bahagian dengan sifat mekanikal yang baik dan lebih ringan. Pemodelan pengkomputeran bagi proses penempaan acuan tertutup, dengan menggunakan kaedah unsur sehingga dan teknik pengoptimuman, membuat reka bentuk pengoptimuman yang lebih cepat dan cekap, mengurangkan penggunaan konvensional kaedah "cuba dan jaya".

Di dalam kajian ini, perisian unsur hingga komersil - ANSYS - telah digunakan untuk model penempaan sejuk acuan tertutup. Model ini telah dikembangkan dengan menggunakan Reka Bentuk Bahasa Parametrik ANSYS (APDL) untuk mensimulasikan tahap tunggal axi-simetri proses penempaan acuan tertutup untuk

bentuk bahagian silang (H). Tempa axissymmetric dengan rusuk web mewakili sekitar 50% dari jumlah output keseluruhan penempaan. Jadi, bentuk H-bahagian silang yang digunakan di dalam kajian ini mempunyai penggunaan aplikasi yang meluas.

Ujian mampatan yang ringkas telah dilakukan untuk aluminium aloi 6061 bagi mengetahui keluk alirannya. Eksperimen penempaan acuan tertutup telah dilakukan dengan menggunakan aluminium aloi 6061 dan eksperimen telah disimulasikan untuk mengesahkan model yang mempunyai kecacatan yang besar. Keputusan simulasi menunjukkan output yang sama dengan yang keputusan daripada eksperimen Sebagai hasilnya, model ini boleh digunakan untuk mensimulasikan penempaan acuan tertutup untuk Al-MMC bahan penguat.

Bahan Al_MMC yang digunakan adalah AlMgSi matrik dengan 15% isi padu zarah SiC, keluk alirannya dan terikan patah yang diperolehi daripada bacaan. Pengoptimal ANSYS digunakan untuk mendapatkan ketinggian maksimum bagi bahan supaya dapat mengalir di rusuk dengan merubah pembolehubah rekabentuk (VD) dan pembolehubah tetap (SV). Umumnya, reka bentuk pembolehubah dan geometrik parameter seperti; nisbah ketinggian rusuk kepada lebar, nisbah tinggi web kepada tinggi rusuk, radius filet, sudut draf dan radius bilet. Pembolehubah tetap (SV) adalah sebahagian parameter yang bergantung kepada reka bentuk pembolehubah seperti; terikan yang seimbang yang harus di bawah terikan patah bahan AMC, dan jurang jarak yang boleh diterima (di dalam toleransi yang dibenarkan).

Objektif daripada kajian ini adalah untuk mencapai bentuk acuan dan diameter bilet yang optimum di dalam pertimbangan penuh pengisian acuan dan juga pengaruh kecacatan aliran besi dari Besi Aluminium Matrik Komposit dalam proses penempaan acuan tertutup tunggal. Pakej unsur hingga komersial yang boleh didapati (ANSYS) digunakan untuk menyiasat kesan kecacatan penempaan acuan tertutup terhadap bentuk acuan dan diameter bilet. Kaedah optimasi yang disebut "Kaedah Sub-Masalah Aproksimasi" telah digunakan untuk mengetahui set reka bentuk yang optimum.

Ketinggian rusuk maksimum diperolehi pada peringkat tunggal penempaan acuan tertutup cakera berbentuk keratan rentas-H yang diperbuat daripada matriks AlMgSi dengan 15% isipadu butiran SiC adalah 0.185 dari bahagian radius terakhir ditempa. Percubaan untuk mendapat ketinggian rusuk yang lebih tinggi menyebabkan regangan yang lebih tinggi dan rekahan akan terjadi di kawasan-kawasan filet. Lebar rusuk dan tinggi web adalah 0.218 dan 0.3 dari bahagian radius terakhir ditempa secara serentak. Ketinggian bilet secara optimum adalah 0.99 dari bahagian radius terakhir ditempa. Radius bilet adalah berkadaran kepada isi pada acuan berongga dan ketinggian bilet. Teknik -teknik yang digunakan dalam kajian ini boleh digunakan untuk bahan yang baru dibangunkan untuk menyiasat kemampuan menempa untuk bentuk yang lebih rumit dalam proses penempaan acuan tertutup

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APPROVAL SHEETS

I certify that an Examination Committee has met on **22/10/2010** to conduct the final examination of Mohamed A. Abdulmawlla on his PhD thesis entitled "Finite Element Analysis and Optimization of Closed Die Forging Process of Al-MMC" in accordance with Unversiti Pertanian Malaysia (HIGHER Degree) Act 1980 and Universiti Pertanian Malaysia (High Degree) Regulation 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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Date: **22/10/2010**

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement 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 institutions.

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MOHAMED A. ABDULMAWLLA

Date: **22 October 2010**

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