UNIVERSITI PUTRA MALAYSIA

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By

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May 2012

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The complication of casting processes are known to be a significant influence on the overall of production cost. The successful of casting processes need knowledge in preparing of molds and patterns, melting and pouring, thermal and molten metal flow, solidification, and casting quality. Thermal expansion in the casting process is one of the most important parameters that influence the casting quality. Metal matrix composites (MMC's) are engineered materials comprised of an alloy matrix and composite reinforcement that is embedded and transformed to improve the material property. Among several metal matrices composites, aluminium silicon carbide is selected because of its advantages such as elevated temperature, weight reduction and fatigue life improvement. However, the actual cast specimens or products are needed to be fabricated to analyze the mechanical properties of the cast metal matrix such as impact strength and yield strength. The purpose of this practice is to ensure casted aluminium silicon carbide to meet the expected strength and fatigue life. This

lead to higher cost consumption and lead time at the design stage of casting product. Furthermore, the thermal behaviors in casting processes follow the non linear condition. The future trend of the current issue is how to predict the thermal behavior of metal matrix composite material in non linear condition by casting process without any experiments. The main objective of this research is to develop the non linear thermal expansion model for casted aluminium silicon carbide. In this research work, the non linear thermal expansion model for casted aluminium silicon carbide material is developed by the squeeze casting method. Three casting processes are applied in this research project, namely sand casting, low pressure die casting, and investment casting. Design case studies in casting processes are developed to present the thermal expansion behavior in low pressure die casting, investment casting, and sand casting. Experimental work of production tooling for aluminium silicon carbide is performed by sand casting process. The casting quality on surface roughness and dimensional accuracy are performed by using the appropriate equipments. It is observed that the result of testing on surface roughness and dimensional accuracy are complying with the standard in the sand casting process. The non linear thermal expansion model is developed for metal matrix composite material. The Coefficient of Thermal Expansion (CTEs) of aluminium silicon carbide fiber reinforced material is significantly influenced by the thermal stresses and interfaces between matrix and fibers. It is found that the thermal expansion behavior of the casted aluminium silicon carbide fiber reinforced composite relies on the thermal expansion of the fibers, and influenced by the onset of interfacial strength and residual stress state.

The validation is conducted among the model, Rule of Mixture (ROM), and experimental result of LM6 alloys silicon reinforces, and showed a good agreement. The obtained Pearson's, Kendall's, and Spearman's correlations value are 0.740, 0.949, and 0.975, respectively. It is concluded that coefficient of thermal expansion (CTE) has positive correlation with surface roughness (Ra). There is a statistically significant negative relationship between CTE and dimensional accuracy. The obtained Pearson's, Kendall's, and Spearman's correlations value are -0.670, -0.949, and -0.975, respectively. It is concluded that when the amount of CTE increases, the dimensional accuracy is improved. In order to determine the performance of the model, the analysis of variance (ANOVA) is presented by using SPSS. It is concluded that there is no statistically different in accuracy between the experiment and the model. In addition, the test of inter-item correlation matrix shows the correlation at the high level of accuracy 99.9% (confidence level of 95%) between the experiment and the model.

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

PEMBANGUNAN BUKAN LINEAR PENGEMBANGAN HABA UNTUK BENTUKAN ALUMINIUM SILIKON KARBIDA

Oleh

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Komplikasi proses penuangan dikenali sebagai pengaruh penting kepada keseluruhan kos pengeluaran. Kejayaan proses penuangan perlu pengetahuan dalam menyediakan acuan dan corak, cairan dan penuangan, logam aliran haba dan lebur, pemejalan, dan kualiti penuangan. Pengembangan haba dalam proses penuangan adalah salah satu parameter yang mempengaruhi kualiti penuangan. Komposit matriks logam (MMC) adalah bahan kejuruteraan yang terdiri daripada matriks aloi dan tetulang komposit yang tertanam dan berubah untuk memperbaiki sifat bahan. Antara beberapa logam matriks komposit, aluminium silikon karbida dipilih kerana kelebihan seperti suhu, pengurangan berat badan dan meningkatkan hayat lesu. Walau bagaimanapun, spesimen cast sebenar atau produk perlu direka untuk menganalisis sifat mekanik logam tuang matriks seperti kekuatan impak dan kekuatan alah. Tujuan amalan ini adalah untuk memastikan bentukan aluminium silikon karbida untuk memenuhi kekuatan yang dijangkakan dan hayat lesu. Ini membawa kepada penggunaan kos

yang tinggi dan masa menerajui pada peringkat rekabentuk penuangan produk. Selain itu, kelakuan haba dalam proses penuangan mengikut keadaan bukan linear. Trend masa depan isu semasa adalah bagaimana untuk meramalkan kelakuan haba untuk logam bahan komposit matriks dalam keadaan bukan linear dengan penuangan proses tanpa sebarang eksperimen. Objektif utama kajian ini adalah untuk membangunkan model bukan linear pengembangan haba untuk bentukan aluminium silikon karbida. Dalam kerja penyelidikan ini, model bukan linear pengembangan haba untuk bentukan aluminium silikon karbida dibangunkan dengan menggunakan teknik acuan himpitan. Tiga proses penuangan diaplikasikan dalam projek penyelidikan ini, iaitu penuangan pasir, penuangan beracuan tekanan rendah, dan penuangan pelaburan. Kajian kes rekabentuk dalam proses penuangan dibangunkan untuk membentangkan kelakuan pengembangan haba dalam penuangan beracuan tekanan rendah, penuangan pelaburan dan tuangan pasir. Kerja eksperimental peralatan pengeluaran untuk aluminium silikon karbida dilakukan dengan menggunakan proses tuangan pasir. Kualiti penuangan kepada kekasaran permukaan dan ketepatan dimensi dilakukan dengan menggunakan peralatan yang berkaitan. Adalah diperhatikan bahawa hasil ujian terhadap kekasaran permukaan dan ketepatan dimensi mematuhi piawaian dalam proses tuangan pasir. Ia adalah berpotensi menggunakan aluminium silikon karbida untuk bahan alat pengeluaran. Model linear pengembangan haba yang bukan dibangunkan untuk bahan komposit matriks logam. Pekali Pengembangan Haba (PKP) bertetulang gentian matriks logam bahan komposit ketara dipengaruhi oleh tekanan antara muka dan haba antara matriks dan gentian. Ia didapati bahawa tingkah laku pengembangan haba untuk bentukan aluminium silikon karbida bergantung kepada pengembangan haba gentian, dan dipengaruhi oleh bermulanya kekuatan antara muka dan keadaan baki tegasan. Pengesahan dijalankan antara model, Kaedah Campuran (ROM), dan hasil eksperimen LM6 silikon aloi mengukuhkan, dan menunjukkan satu perjanjian yang baik. Nilai korelasi Pearson, Kendall, dan Spearman diperolehi masing-masing ialah 0,740, 0,949, dan 0,975. Ini dapat disimpulkan bahawa pekali pengembangan haba (CTE) mempunyai hubungan yang positif dengan kekasaran permukaan (Ra). Terdapat hubungan statistik negatif yang signifikan antara CTE dan ketepatan dimensi. Nilai korelasi Pearson, Kendall, dan Spearman diperolehi masing-masing ialah -0,670, -,949, dan -0,975. Ini dapat disimpulkan bahawa apabila jumlah CTE mengalami kenaikan, ketepatan dimensi akan bertambah baik. Untuk menentukan prestasi model, analisis varians (ANOVA) dibentangkan dengan menggunakan perisian SPSS. Ini dapat disimpulkan bahawa terdapat kesamaan secara statistik antara eksperimen dan model. Di samping itu, ujian matriks korelasi antara item menunjukkan korelasi pada tahap ketepatan yang tinggi 99.9% (tahap keyakinan 95%) antara eksperimen dan model.

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LIST OF ABBREVIATIONS

Al	Aluminium
Si	Silicon
C	Carbon
Mn	Manganese
Cu	Copper
P	Phosphorous
S	Sulphur
Zn	Zinc
l	length (mm)
h	height (mm)
m	mass (kg)
L	thickness (mm)
ρ	Electrical resistivity, ohm-m
σ	Electrical conductivity, [1/ ohm-m]
MPa	Mega Pascal
GPa	Giga Pascal
KN	Kilo Newton
MMC	Metal matrix composite
SiO_2	Quartz (Silicon dioxide)
LM6	Aluminium 11.8% Silicon alloy
µm	Micrometer (micron)
T	Ton

Wt %	Weight %
α	Thermal diffusivity (cm^2/sec)
λ	Thermal conductivity (W/m k)
α_l	CTE, Linear thermal expansion coefficient ($^0C^{-1}$)
$V\alpha$	Volumetric expansion
K_{1C}	Fracture toughness (MPa m ½)
SiC	Silicon carbide
P_a	pressure at point *a*
P_M	value of the pressure at point *M*
g	gravity
h	height
V_M	velocity at point *M*
Q	flow rate
A	cavity area
A_R	cross section stalk
t	time
t_s	time at stalk
$X(t)$	position of stalk as any given time
L	walls of the channel
u	stalk velocity
c	speed of the wave
dt	time step (s)

Greek letters

β propagation constant

ρ density

Subscript

0 initial

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