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Mehdi Moayyedian

Intelligent Optimization of Mold Design and Process Parameters in Injection Molding

Doctoral Thesis accepted by
University of South Australia, Adelaide, Australia

Springer

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I specially dedicate this thesis to my family who have supported me throughout the entire doctorate program

Supervisor's Foreword

Among different technologies in the manufacturing of plastic products, injection molding is the most significant technology which covers most of the industrial applications. The main factors used to evaluate the quality of injected parts are *part design*, *material characteristics*, *mold design*, and *process parameters*. Hence, reliable design and optimization of injection molding process are essential.

Part design heavily depends on the customer requirements for which more than 17,000 plastic materials are used throughout the world; hence, *part design* and *material characteristics* are not considered herein. Therefore, it is desirable to find the effect of *mold design* and *process parameters* on injection molding to improve the quality of injected parts leading to the reduction of scrap rate.

Dr. Mehdi Moayyedian's thesis was mainly dedicated to understanding the interrelationship of process parameters, mold design, and fabricated plastic parts integrity during injection molding. Such knowledge can be used as the basis of ways to improve the quality of injected parts. He designed some new runner and gate geometries of different dimensions and employed predictive tools to study the defects formation during injection molding. The possibility of the formation of a range of molding defects including *warpage*, *weld line*, and *short shot* along with *moldability index* was studied. He further attempted to identify the most influential process parameters and mold design geometries on the integrity of fabricated plastic parts by using a combination of simulation modeling tools and methods namely SolidWorks, SolidWorks Plastic, Taguchi method, finite element analysis (FEM), fuzzy logic method, analysis of variance (ANOVA), analytic hierarchy process (AHP), Technique for Order Performance by Similarity to Ideal Solution (TOPSIS), fuzzy AHP (FAHP), and fuzzy TOPSIS (FTOPSIS). A strength of his work is the application of these tools and methods in the last two chapters to solve a multi-objective problem to determine the higher and highest *moldability index* by considering three different common defects and five different geometric and process parameters of three different levels.

Dr. Moayyedian has demonstrated that he has gained significant knowledge and experience in applying these tools in this research and demonstrated very good agreements between (finite element) modeling and experimental results which validated the robustness of his assumptions, methodology, and algorithm.

Adelaide, Australia
July 2018

Prof. Kazem Abhary

Parts of this thesis have been published in the following articles

Journal papers

1. Moayyedian, M., Abhary, K. and Marian, R., Gate design and filling process analysis of the cavity in injection molding process. *Advances in Manufacturing*, pp. 1–11.
2. Moayyedian, M., Abhary, K. and Marian, R., Elliptical cross sectional shape of runner system in injection mold design. *International Journal of Plastics Technology*, pp. 1–16.
3. Moayyedian, M., Abhary, K. & Marian, R., 2017, 'The analysis of short shot possibility in injection molding', *International Journal of Advanced Manufacturing Technology*, pp. 1–13.
4. Moayyedian, M., Abhary, K. & Marian, R., 2016, 'The Analysis of Defect Prediction in Injection Molding', *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, pp. 1819–1822.

Peer-reviewed conference papers

1. Moayyedian, M., Abhary, K. and Marian, R., 2015. Improved gate system for scrap reduction in injection molding processes. *Procedia Manufacturing*, *2*, pp. 246–250.
2. Moayyedian, M., Abhary, K. and Marian, R., 2015. New Design Feature of Mould in Injection Molding for Scrap Reduction. *Procedia Manufacturing*, *2*, pp. 241–245.

Declaration

I hereby declare that this Ph.D. thesis entitled "The effect and intelligent optimization of mold design and process parameters in injection molding" was carried out by me for the degree of Doctor of Philosophy under the guidance and supervision of Prof. *Kazem Abhary* and Dr. *Romeo Marian*, School of Engineering, University of South Australia. This thesis contains no material that has been submitted previously in whole or in part, for a degree or diploma in any university. Except where otherwise indicated, this thesis is my own work.

Adelaide, Australia
May 2017

Mehdi Moayyedian

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Contents

Abbreviations

ABS	Acrylonitrile–butadiene–styrene
AHP	Analytic hierarchy process
ANOVA	Analysis of variance
CAD	Computer-aided design
CAE	Computer-aided engineering
CNC	Computer numerical control
CT	Cooling time
DMAIC	Define, measure, analyze, improve and control
DOE	Design of experiment
FAHP	Fuzzy analytic hierarchy process
FEA	Finite element analysis
FEM	Finite element method
FNIS	Fuzzy negative ideal solution
FPIS	Fuzzy positive ideal solution
FTOPSIS	Fuzzy technique for order performance by similarity to ideal solution
HDPE	High-density polyethylene
LDPE	Low-density polyethylene
MS	Mean square
MSD	Mean square deviation
MT	Mold temperature
PC	Percentage of contribution
PIM	Plastic injection molding
PP	Packing pressure
PP	Polypropylene
PS	Polystyrene
PT	Packing time
PVC	Polyvinyl chloride
RSM	Response surface methodology

SCF	Supercritical fluid
SN	Signal to noise
SW	Shrinkage and warpage
TOPSIS	Technique for order performance by similarity to ideal solution

Symbols

S	Total surface area of the product
C_1	Empirical factor of wall thickness
d	Gate diameter
C_2	Empirical factor of different materials
D_R	Runner diameter
W	Weight of the product
L	Length of the runner
$\dot{\gamma}$	Shear rate
$\dot{Q}$	Flow rate
η	Viscosity of material
P	Pressure drop
τ	Maximum shear stress
r	Radius of runner
w	Width of the gate
n	Material constant
h	Height of the gate
t	Thickness of the injected part
F	Total force
V	Velocity in straight line
v_1	Velocity distribution
H	Gap between the plate
x_2	Movement of the plate in shear rate
Y_i	Defect rate
N	Total number of data points or experiments
df_T	Total degree of freedom
df_A	Degree of freedom of factor A
df_E	Degree of freedom for error variance
SS_A	Sum of square of factor A
SS_T	Total sum of square
SS_E	Sum of square for error variance

x_i	Value at different levels
n_{A_i}	Number of levels
A_i	Value at level i of factor *A*
MS_A	Mean square of factor *A*
MS_T	Total mean square
MS_E	Mean square of error variance
F_A	Value of the *F ratio* of factor *A*
PC	Percentage of contribution
A	Gate type
B	Filling time
C	Part cooling time
D	Pressure holding time
E	Melt temperature
α	Positive factor
β	Negative factor
λ	Regular factor
$S_j(X_j)$	P-dimensional variable weight profit vector
W	Variable weight vector
s	Variable weight state vector
w	Constant weight vector
m	Trial number of experiment
n	Number of injection defects
$\tilde{v}_{ij}$	Normalized positive trial numbers
A^+	Fuzzy positive ideal solution
A^-	Fuzzy negative ideal solution
d_i	The distance of each alternative or experiments
$\mathrm{Q}I_i$	Quality index of the *n* alternative
$\tilde{\alpha}_1$	Rating the seriousness (very low)
$\tilde{\alpha}_2$	Rating the seriousness (low)
$\tilde{\alpha}_3$	Rating the seriousness (medium)
$\tilde{\alpha}_4$	Rating the seriousness (high)
$\tilde{\alpha}_5$	Rating the seriousness (very high)
$\tilde{\mathrm{R}}$	Fuzzy relative matrix
$\tilde{\mathrm{V}}$	Varied weight fuzzy evaluation matrix
$\tilde{\mathrm{W}}$	Constant weight factor matrix
MI_i	Moldability index
D'	Diameter of injected parts before shrinkage
D''	Diameter of injected parts after shrinkage
K_A	Number of level for factor A