SIMULATION BASED OPTIMIZATION OF INDIRECT ALUMINUM EXTRUSION PROCESS PARAMETERS

Sachin Man Bajimaya, Chang Mok Park and Gi-Nam Wang
Ajou University
Department of Industrial & Information Systems Engineering
Suwon, 443-749, South Korea
E-mail: {sachin, cmpark, gnwang}@ajou.ac.kr

KEYWORDS
Extrusion, Simulation, Optimization, IGRIP

ABSTRACT

The objective of this paper is to optimize the principal extrusion variables by means of manufacturing simulation of the extrusion model. The finite element analysis of the extrusion model does not consider the manufacturing process in its modeling. Therefore, the process parameters obtained through such an analysis remains highly theoretical in that these parameters differ from the actual extrusion process parameters. Additionally, due to the nature of the extrusion process, it is often quite difficult to determine the cause of an extrusion problem and find its proper solution, particularly if it must be done quickly. The manufacturing simulation of the extrusion process prior to plant execution helps to make the actual extrusion operation more efficient because more realistic parameters may be obtained through the simulation. Additionally, troubleshooting the process becomes simpler. In this paper, we have developed the simulation model of a real extrusion plant using IGRIP. The model of the plant is simulated in IGRIP using the Graphical Simulation Language (GSL). The dynamics of the plant is also incorporated in the simulation model. Through simulation, optimized values of variables that affect the extrusion process are obtained.

INTRODUCTION

One of the greatest challenges in an actual extrusion operation is efficient and rapid problem solving. However, the conventional finite element analysis does not consider the manufacturing process constraints in its modeling and hence, the process parameters obtained through such an analysis is more theoretical and not realistic enough. Therefore, a new approach to obtain more realistic and optimized process parameters following the finite element analysis is the need of manufacturing industries.

Extrusion problems often result in downtime and/or out-of-specification products, and this can be very costly. The nature of the extrusion process is often complex. Therefore, the determination of an appropriate solution to the cause(s) of any problem in the extrusion process is difficult, particularly if the solution must be found quickly. Linear programming and other iterative methods have been used to tackle the extrusion process problems. However, due to the inherent time consuming nature of such methods, quick and rapid problem solving as desired by industries has not been achievable. Additionally, today, the process development in industrial extrusion is to a great extent based on trial and error and often involves full-size experiments, which are both expensive and time-consuming. In contrast, simulation of the extrusion process prior to plant execution and as and when required, proves to solve the extrusion operation problems quickly and more efficiently and at a lower cost. In this paper, model of a real extrusion plant is built in IGRIP, a Delmia group software from Dassault Systems [12]. The model of the plant is simulated in IGRIP using the Graphical Simulation Language (GSL) whereby the virtual operation of the plant may be viewed. Additionally, the dynamics module offered by Delmia is used to model and simulate the extrusion plant dynamics. Simulation is performed to obtain the optimized values of the principal variables that affect the extrusion process.

BACKGROUND

Sivaprasad, Venugopal, Davies and Prasad [7] have identified the optimum process parameters using finite element simulation. They discuss the use of processing map with the output of the finite element analysis to design the process. Tibbetts and Ting-Yung [8] have used optimization technique for a direct extrusion machine. Their work is related to product optimization with focus on surface quality and micro-structural uniformity of product. They have presented a model which is derived directly from the mathematical description of the physical phenomena present. Hansson, in her Ph.D. thesis [9], has used finite elements method for the simulation of stainless steel tube extrusion.

Most other extrusion process simulations have been done for food industries like by Lertsiriyothin and Kumtib [10], and plastic or polymer manufacturing units such as by Salazar [11].

Plenty of studies related to finite element-based models and mathematical descriptions as mentioned above have already been carried out. The finite element models provide the needed information but cannot be applied for direct and fast decision making. The finite element

Proceedings 21st European Conference on Modelling and Simulation
Ivan Zelinka, Zuzana Oplatková, Alessandra Orsoni ©ECMS 2007
ISBN 978-0-9553018-2-7 / ISBN 978-0-9553018-3-4 (CD)

analysis, in particular, does not consider the manufacturing process in its modeling and so, the process parameters obtained through such an analysis differs form the actual manufacturing process parameters. In such a scenario, following the finite element analysis, optimization of process parameters based on the manufacturing simulation of the process yields a direct solution for the real process in that the appropriate process parameters can be recognized directly. The indirect extrusion simulation for the optimization of process parameters dealt with in this paper is thus found to be new and the simulation-based approach is found to be novel in the area. Such an approach is found to provide quick and efficient solution to extrusion problems.

INDIRECT EXTRUSION

The extrusion process

Extrusion is a plastic deformation process in which a block of metal, called the billet, is forced to flow by compression through the die opening of a smaller cross-sectional area than that of the original billet [4] as shown in Fig. 1. In indirect extrusion process, the die at the front end of the hollow stem moves relative to the container, but there is no relative displacement between the billet and the container as depicted in Fig. 1. Therefore, this process is characterized by the absence of friction between the billet surface and the container, and there is no displacement of the billet center relative to the peripheral regions.

Extrusion can be cold or hot. In this paper, we consider the hot extrusion process. In hot extrusion, the billet is preheated to a certain temperature to facilitate plastic deformation.

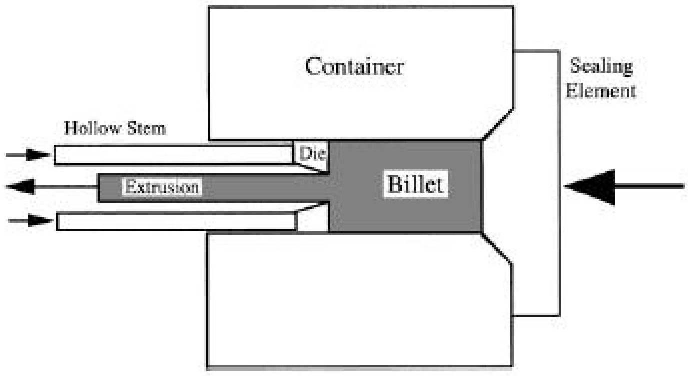

Figure 1: Indirect extrusion mechanism

The properties of the extruded aluminium shapes are affected greatly by the way in which the metal flows during extrusion. The metal flow is influenced by several factors of which the following are considered in this paper:

1. the size of billet (length and diameter)
2. the temperature of billet, $\theta_{preheat}$
3. the temperature of container
4. the extrusion ratio, ER
5. speed of extrusion, $V_{extrusion}$
6. the extrusion pressure, $P_{T(ER)}$

Interdependence between extrusion variables

During the operation of an extrusion plant, while extrusion is taking place, billets will be waiting for their turn to get loaded to the container for extrusion. In hot extrusion, the billets are preheated. It should be assured that the next billet in queue is heated to the required preheat temperature ($\theta_{preheat}$) during the time (τ_{wait}) it waits in the queue. For efficient heat usage, τ_{wait} would be approximately equal to the sum of the time taken by the current billet to be extruded ($\tau_{extrusion}$) and the time taken for the change of die ($\tau_{dieChange}$). Therefore, considering the time taken to preheat to be $\tau_{preheat}$,

$$\tau_{preheat} = \tau_{wait} = \tau_{extrusion} + \tau_{dieChange}$$

Temperature is one of the most important parameters in extrusion. The flow stress (σ) is reduced if the temperature is increased and deformation is therefore, easier, but at the same time, the maximum extrusion speed is reduced because localized temperature can lead to incipient melting temperature.

The response of a metal to extrusion processes can be influenced by the speed of deformation. Increasing the ram speed produces an increase in the extrusion pressure. The temperature developed in extrusion increases with increasing ram speed.

Thus, it is important to determine the optimal values of the principal extrusion variables for a specified extrusion ratio (ER) such that, while on the one hand, the aluminum billet does not reach its solidus point ie, it’s melting temperature, and on the other hand, efficient extrusion is assured. Extrusion ratio (ER) is the ratio of container bore area to the total cross-sectional area of extrusion. For an extrusion process, ER is fixed.

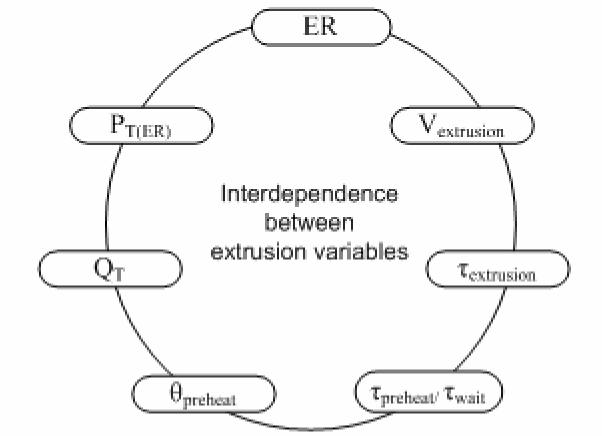

Figure 2: Interdependence between extrusion variables

Determination of ram speed ($V_{extrusion}$) is the most important for a particular extrusion ratio. The ram speed affects the extrusion time ($\tau_{extrusion}$). The preheat time

($\tau_{preheat}$), in turn, is related to the extrusion time. Therefore, simulation is performed for a specific extrusion ratio and speed of ram to obtain the extrusion time. The extrusion time is used to decide the amount of heat (Q_T) that a waiting aluminum billet should be given to reach the preheat temperature ($\theta_{preheat}$) during the period of its waiting time (τ_{wait}).

The actual pressure exerted on the ram is the total pressure. The total extrusion pressure required for a particular extrusion ratio (ER) is given by:

$P_{T(ER)} = P_D + P_F + P_R$

where, P_D is the pressure required for the plastic deformation of the material. P_F is the pressure required to overcome the surface friction at the container wall friction, dead metal zone friction, and die bearing friction. P_R is the pressure required to overcome redundant or internal deformation work.

Each of the above may be represented in functional form as:

P_D = **f** (flow stress σ, strain ε)

where, the flow stress σ = **f** (strain ε, strain rate, temperature of material T).

Here, strain $\varepsilon = \ln(A_C/A_E)$ where, A_C = area of container and A_E = area of extrusion

P_F = **f** (billet diameter D, length of billet L)

P_R = **f** (flow stress σ)

The extrusion pressure, $P_{T(ER)}$, is thus dependent upon the size of the billet, the extrusion ratio, the temperatures of billet and container, flow stress and the strain rate of aluminum. The pressure, $P_{T(ER)}$, so obtained is used to find the extrusion speed ($V_{extrusion}$). Generally, a chart is provided by the extrusion machine manufacturer that gives the extrusion speed required to produce a particular extrusion pressure P_T at a specified temperature and extrusion ratio (Fig. 3, 4 and 5). The extrusion speed may be utilized to find the extrusion time ($\tau_{extrusion}$). The extrusion time, in turn, may be used to find the time required by an aluminum billet to wait (τ_{wait}) before it gets loaded to the container for extrusion. This amount of time is used to find the amount of heat (Q_T) that should be supplied to the aluminum billet during this time (τ_{wait}) to reach its preheat temperature ($\theta_{preheat}$). The values of $\theta_{preheat}$ and $V_{extrusion}$ should be such that the aluminum billet does not reach its solidus temperature, which is approximately 660ºC [3], during the actual extrusion process; which is to say, after the $V_{extrusion}$ is known, $\theta_{preheat}$ should be so selected as to ensure that the aluminum billet does not reach its solidus temperature during extrusion.

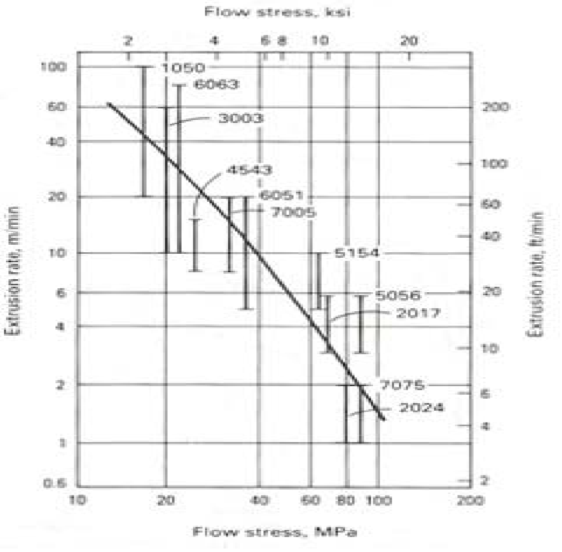

Figure 3: Extrusion rate versus flow stress

The values of the principal variables so obtained may be valid only for theoretical use. In reality, the values of these variables may differ for a practical extrusion process. Also, these values may not be within the permissible values of a particular extrusion machine. So, a simulation is performed, considering the dynamics of the process – stress and strain factors, changes in temperature and pressure, the friction and speed of extrusion – and the permissible value of process parameters to validate the process with the values so obtained.

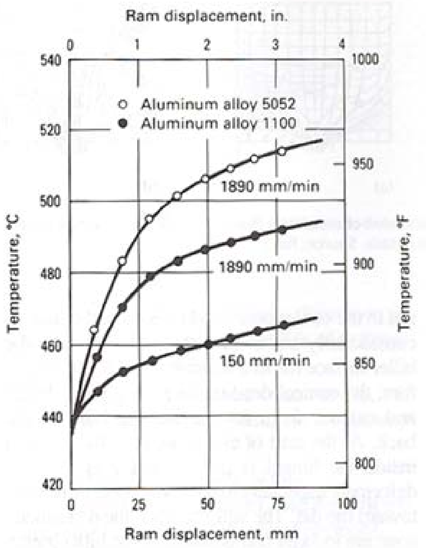

Figure 4: Surface temperature of extruded product versus ram displacement

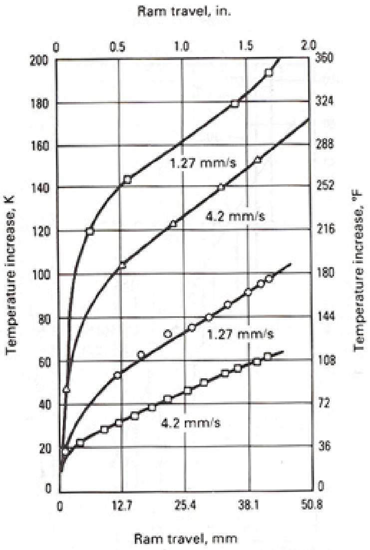

Figure 5: Increase in emergent temperature versus ram speed

IGRIP offers a dynamics module that facilitates the incorporation of the dynamics of a process. Any necessary changes may then be made and simulation may be performed several times until the values of the variables satisfy usage in a real extrusion process. For example, if after calculations, the billet temperature obtained will lead to the aluminum billet reaching its solidus temperature, then the extrusion speed, $V_{extrusion}$, may be reduced. The reduced extrusion speed may be used to find a different extrusion pressure, $P_{T(ER)}$ and also to calculate the extrusion time, $\tau_{extrusion}$. This extrusion time, in turn, may be used to find the time for the billet to wait, τ_{wait} before it gets loaded to the container for extrusion. Also, the amount of heat, Q_T that has to be supplied to the aluminum billet during τ_{wait} may be calculated.

THE EXTRUSION SIMULATION FRAMEWORK AND IMPLEMENTATION

A graphical model of the extrusion plant is built using IGRIP (Fig. 6). The model is validated against the working of a real machine. The validated model is then simulated using the Graphical Simulation Language (GSL) in IGRIP. The dynamic properties of the extrusion process are taken into account in the extrusion model by making use of the dynamics module in IGRIP.

A client software was built using Visual C++. Values of the principal variables for extrusion are sent as inputs from this client (Fig. 7). The server makes use of these principal variables for the simulation of the extrusion model. Additionally, we developed an interface program between the client and the server so that message sent from the VC++ client is read into the GSL program in the server. The GSL program makes necessary readings from and writings to a database that contains the permissible values of extrusion variables and tables containing the values of extrusion speeds required to produce corresponding extrusion pressures. The database also contains further vendor-specific data regarding extrusion.

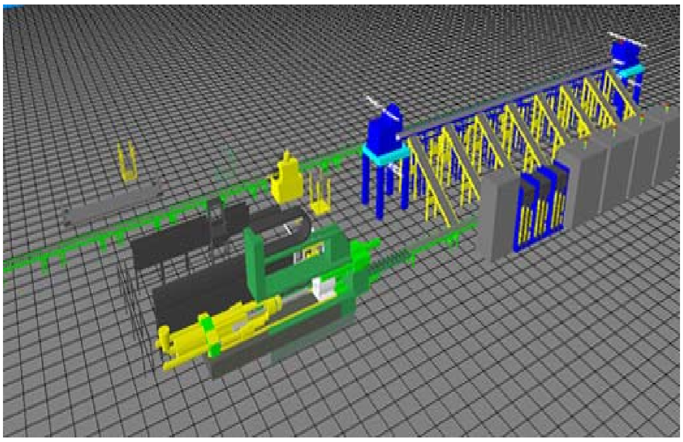

Figure 6: The IGRIP model of the extrusion plant used for simulation

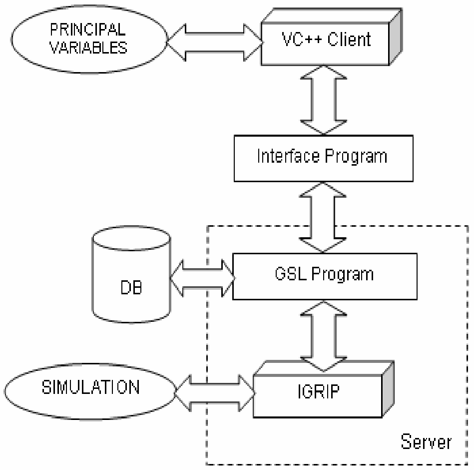

Figure 7: The implementation architecture

The use of the optimized values of the principal extrusion variables in several simulations of the plant resulted in a reduced cycle time of the plant. The minimum decrease in cycle time was 2 minutes which makes a decrease of 8.33 percent whereas the maximum decrease was of 12 minutes that accounts for a 37.5 percent decrease. The average decrease was approximately 5 minutes which is about 20.8 percent (Fig. 8). The power consumed by the complete extrusion operation was also decreased considerably in the simulations of extrusions at varying extrusion ratios (ER). The percentage decrease ranged between a minimum of 4 percent to a maximum of 17 percent with an average of 12.7 percent considering simulations at all extrusion ratios (Fig. 9). The simulation results are highly encouraging to be subsequently applied to a real world extrusion process in the future after considering the product optimization.

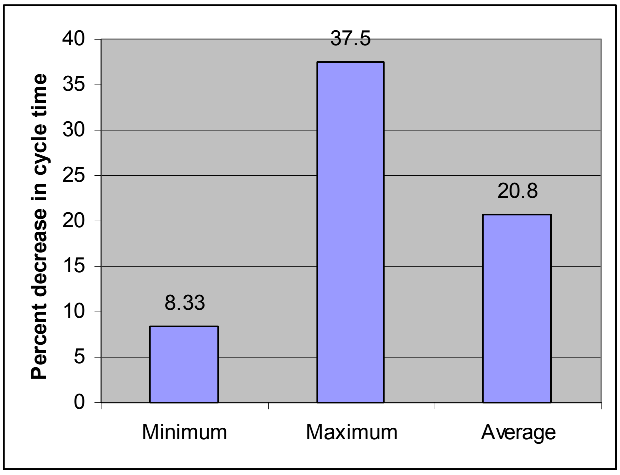

Figure 8: Graph showing percentage decrease in cycle time

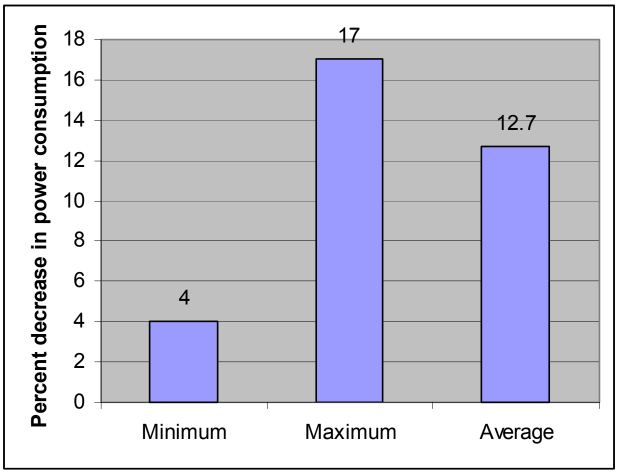

Figure 9: Graph showing percentage decrease in power consumption

DISCUSSIONS AND CONCLUSION

In this paper, the use of simulation for the optimization of principal extrusion variables was discussed. IGRIP and the dynamics module in IGRIP were used to model an actual extrusion machine. The model was then simulated using Graphical Simulation Language. The optimization obtained is positive and better optimization may be attained by considering wider factors that affect the dynamics of the extrusion process. Additionally, corresponding product optimization study will only better the actual optimization process and near the use of simulated data for real extrusion processes.

ACKNOWLEDGMENT

The authors would like to gratefully thank the KRF (Korea Research Foundation), BK21 (Brain Korea 21), and Digital Manufacturing Simulator and OLP System for Automobile Industry, South Korea for the fund that has been provided for this research.

REFERENCES

Banks, J., Handbook of Simulation, John Wiley and Sons Inc, New York, 1998.

Banks, J., Carson J. S., Nelson B.L., and Nicol D.M., Discrete event System Simulation, Prentice Hall, New Jersey, 2005.

Carson, J.S., “Introduction to Modeling and Simulation”, Proceedings of the 2005 Winter Simulation Conference, ed. M.E. Kuhl, N.M. Steiger, F.B. Armstrong, and J.A. Joines, Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Davis, J.R., Aluminum and Aluminum Alloys, ASM Specialty Handbook, ASM International, 1996

Delmia IGRIP Tutorial, Dassault Systems.

Hansson, S., “Simulation of Stainless Steel Tube Extrusion”, Ph.D. Thesis, Department of Applied Physics and Mechanical Engineering , Division of Material Mechanics, Luleå University of Technology, Sweden, 2006

Lertsiriyothin, W. and Kumtib, M., “Simulation of flour flow in extrusion process by using computational fluid dynamics commercial software”, ANSCSE, July 2004

Musselman, K.J., “Guidelines for Simulation Project Success”, Proceedings of the 1994 Winter Simulation Conference, ed. J.D. Tew, S. Manivannam, D.A. Sadowski, and A.F. Seila, Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Rao, P.N., Manufacturing Technology – Foundry, Forming and Welding, Tata McGraw Hill, New Delhi, 1995

Salazar, C.A.G., “Process simulation and training: the case of plastics extrusion”, Journal of Modeling and Simulation in Materials science and Engineering, 1994

Sivaprasad, P.V., Venugopal, S, Davies, C.H.J., and Prasad, Y.V.R.K., “Identification of optimum process parameters for hot extrusion using finite element simulation and processing maps.”, Journal of Modeling and Simulation in Materials Science and Engineering, Institute of Physics Publishing, Feb. 2004

Tibbetts, B.R., and Ting-Yung, J., “Extrusion Process Control: Modeling, Identification, and Optimization”, IEEE transactions on control systems technology, vol. 6, no. 2, March 1998

AUTHOR BIOGRAPHIES

SACHIN M. BAJIMAYA was born in Nepal and went to South Korea to Ajou University in Suwon, where he is studying Industrial Engineering. Currently, he is a Graduate Research Assistant at the Automatic Monitoring and Control Laboratory. His e-mail address is: sachin@ajou.ac.kr.

CHANG M. PARK has a PhD in Industrial Engineering. Currently he is doing his post-doctoral research in the Automatic Monitoring and Control Laboratory in Ajou University, Suwon, South Korea.

GI-NAM WANG is a professor and Head of Department at the Department of Industrial and Information Systems Engineering, Ajou University, Suwon, South Korea. He holds a Ph.D. from Texas A&M University, USA. He has been a visiting professor at the University of Texas at Austin and is a member of many professional engineering societies. Web-page: http://madang.ajou.ac.kr/~gnwang/