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A Computer-Aided System for Life Cycle Assessment of a Pressure Die-Casting Process

Manmohan Singh[1], Ramandeep Singh[2], Jagjeet Singh[3]
[1]*ME Department,CEC, Landran,Mohali*
[2]*ME Department,GZS,PTU Campus,Bathinda*
[3]*ME Department,CEC, Landran,Mohali*

ABSTRACT—*Pressure die-casting parts are widely used in various assemblies so the die-casting products are in huge demand. To meet the increasing demand and increasing manufacturing cost industries are focusing on sustainable manufacturing. Life cycle assessment tools are used by the industries to quantify sustainability of a process. In the present study, a computer aided system to analyze the sustainability of pressure die-casting process is developed. The proposed system can determine indicators like energy use, solid waste, cost, and other miscellaneous consumption like flux, die-coat lubricant for pressure die-casting process. It determines the sustainability indicators on the basis of the selection of metal, metal alloy and sub-process. This system has user friendly Graphical User Interface (GUI).That has been developed to prompt user to select the various choices in the system and enter data for the process plan.The two case studies are presented to verify the computer aided system process analyzer by comparing the system data with actual measured data in industry.*

Keywords *– Casting; pressure die-casting; sustainable manufacturing; sustainability indicator; Life cycle assessment.*

I. INTRODUCTION

Die casting is a widely used high-technology manufacturing process which is both capital and energy dependent. High energy consumption required to cast products warrants attention [3].To reduce the energy consumption and other miscellaneous sustainability analysis is performed on life cycle of manufacturing process. The development of an appropriate assessment method for evaluating the environmental performance of a manufacturing process is one of the keys to realize a successful sustainable manufacturing strategy. Sustainability of a manufactured part is represented using sustainability indicators. A number of indicators are available for sustainable manufacturing and broadly classified into social, economic and environmental indicators [13].According to the flows in the manufacture they are divided into input and output indicators.

Present work focuses on sustainability analysis of pressure die casting process. The sustainability indicators used are energy consumption, solid waste, cost and other miscellaneous consumption.

Pressure die-casting process is energy intensive process. The energy is required to cast the process, so the energy consumption is an indicator for the study. To improve the material efficiency, the solid waste is the second indictor for the study. To improve the material efficiency and to reduce energy consumption with minimum cost, so the cost is the third indictor. Pressure die-casting process consumes other consumables like flux, die-coat lubricant etc. which are considered under fourth indicator namely miscellaneous consumption.

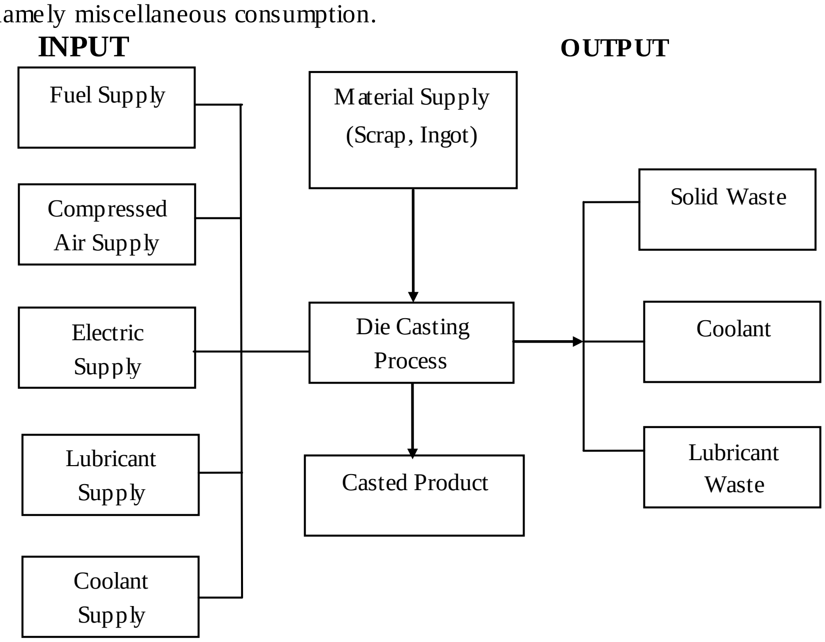


Figure 1: Input and Output indicators

II. RELATED WORK

Previous work related to sustainability analysis of manufacturing processes is discussed in this section. Choi et. al. [5] developed assessment model for manufacturing process to evaluate the product design in terms of environmental impact. Robert et. al. [27] Suggest changes to reduce the environmental impact of aluminium die-casting process. By analyze the life cycle inventory aluminium die-casting process using air emission and material use. Indirect emission caused by the process is not considered. Krajncet. al. [13] proposed the indicators for sustainable production. Indicators are based on commonly measured environmental aspects of sustainable production. Tanet. al. [21] Use Life Cycle Analysis (LCA) to investigate the environmental performance of zinc cast product. Direct and indirect air emission that arises from zinc smelting, casting, recycling and during transportation has been measured. The results confirmed that the major air pollution occurs during smelting 65-70% of overall air pollution during the process. Gutowskiet. al. [7] performed the system level environmental analysis on pressure die-casting process. Environmental impact is evaluated by examining the life cycle of the process considers the die preparation, metal preparation, casting and trimming. Narita et. al. [17] proposed an environmental burden analyzer for machine tool operation. Analysis is based on tool wear information and cutting conditions from the viewpoints of environmental burden due to electric consumption of machine tool components, coolant quantity, and lubricant oil quantity, cutting tool status, metal chip quantity and other factors. Neto B. et. al. [18] developed a model (MIKADO) that can be used to evaluate the environmental performance. Methodology used to develop the model is based on life cycle assessment of the part and environmental system management. This model does not consider the indirect air emission. Jiang et. al. [11] proposed the method to evaluate the environmental performance for manufacturing process plan. A matrix is used whose row corresponds to process and column is associated with environmental performance criterion and the normalized inventory values are used to create a score for each process and criterion. The method has been encoded into the software. It evaluates the environmental performance as waste emission and energy consumption only. Singh et. al. [28] Proposed sustainability analyzer for die-casting process is presented using three sustainable indicators (air emission, energy use and solid waste). It helps the die-casting industry to improve the energy efficiency and to reduce the air emission and solid waste. The proposed system uses analytical method to calculate the sustainability indices and is compared with shop floor data. The proposed system is limited to three indicators to analyze the sustainability. Balogunet et. al. [2] Develops a new mathematical model for predicting direct energy required for machining. By study the effects on electric current consumed during machining due to machine modules, auxiliary units and machine code and evaluate the tool path to makes them more efficient.The number of studies on the environmental performance of the metal casting is limited.

III. COMPUTER AIDED SYSTEM MODULES

The computer aided system has three modules (Input module, Processing module, Output module). Input module consists of parameters entered by user into the input panels of the system. Input parameters are Mass of charge , ambient temperature, Final temperature, Furnace efficiency , Power rating of holding furnace, Time, Shot weight, Surface area of product, Number of products produce, Cycle time, Load capacity of fork-lifter, Distance between machine and melting furnace, Number of lights in use and Power rating of furnace blower, coolant pump, air compressor, lights and fans etc. This module processes the input data entered by user and the database data using some empirical formula and logic relation. It takes the values from input variables and relevant data from database according to the selection machines, metal, metal alloy and process plan etc. After processing the data the generated data is displayed by output variables. The data generated by the processing module is displayed on screen by output module. This generated data can be presented in the form of graph.

IV. SYSTEM INPUT AND OUTPUT PARAMETERS

In the system some parameters are to be entered by the user and system will calculated the sustainability indicator as output parameters shown in table 1.

Table 1: Input and output parameters of computer aided die-casting process analyzer

Sub-processes of die-casting	Input parameters	Output parameters

Metal melting and holding	Mass of charge (in kg) Ambient temperature Final temperature Furnace efficiency (%) Power rating of holding furnace (in kW) Time (in hours)	Fuel consumed Electricity consumed Flux consumed Solid waste
Pressure die-casting process	Shot weight Surface area of product Number of products produce Cycle time	Electricity consumed Solid waste Die-coat lubricant consumed
Macro-level activities	Load capacity of fork-lifter Distance between machine and melting furnace Number of lights in use Power rating of furnace blower Power rating of coolant pump Power rating of air compressor Power rating of lights Power rating of fans	Fuel consumed by fork-lifter Electricity consumed by furnace blower, Electricity consumed by coolant pump Electricity consumed by air compressor Electricity consumed by lights Electricity consumed by fans

V. WORKING OF THE SYSTEM

The system flow chart shows the steps involved in the proposed computer aided die-casting process analyzer. The flow chart of the system is shown in figure 2. The first step is to select the metal of casting product the system will read the alloy data under the chosen metal from database and show the alloys in alloy dropdown menu. The second step is to select alloy for the product. The third step is to select process plan like pressure die-casting process, gravity die-casting process etc. After selecting the process plan the user have to select sub-process and enter the required data and system will retrieve the other data from database. After entering the data the system will generate results and display in main form along with graph.

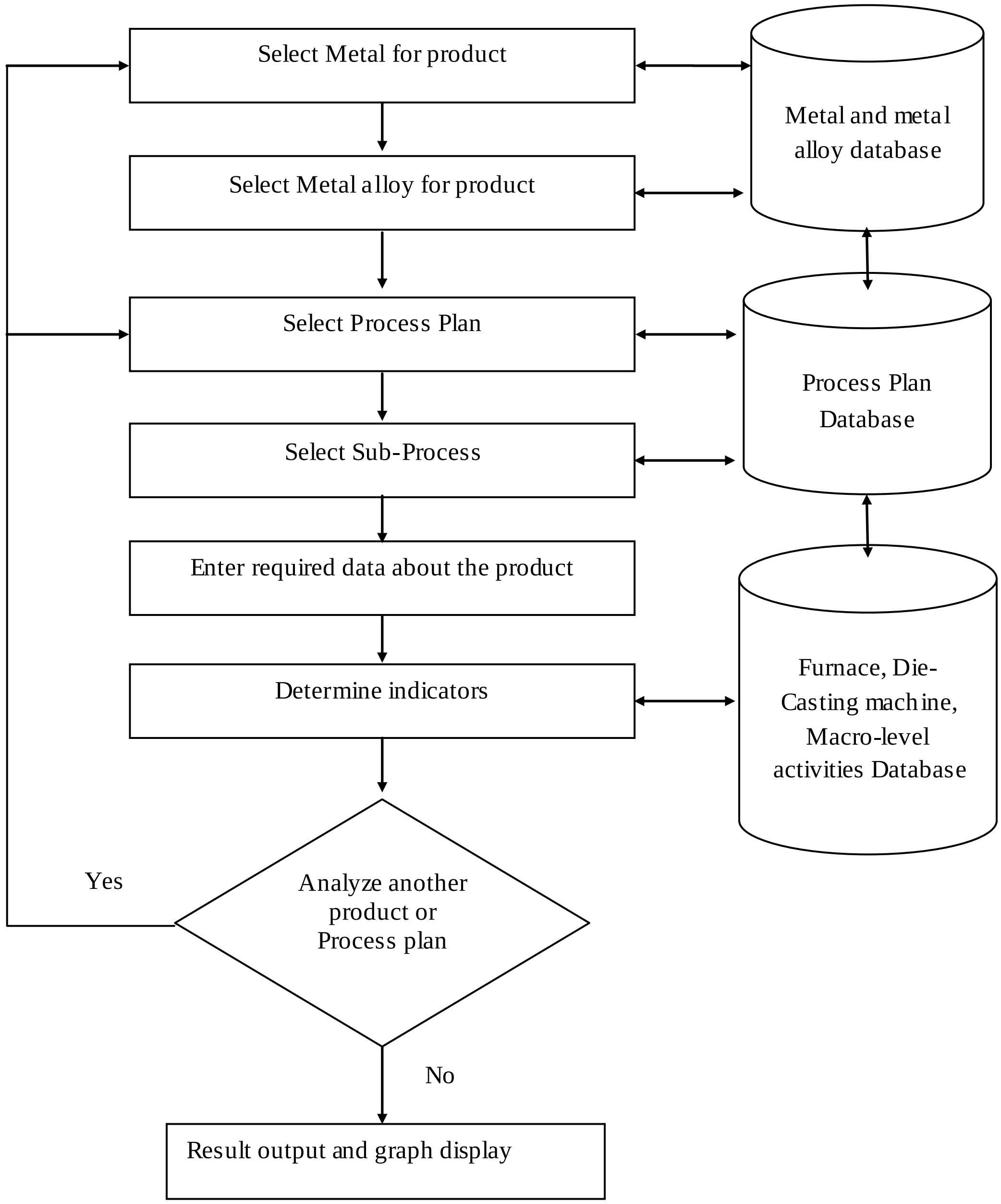


Figure 2: System flow chart

VI. SYSTEM IMPLEMENTATION AND RESULTS

To present the usefulness of the prosed computer aided die-casting process analyzer, the case studies are presented in this chapter. The proposed system requires some data to be entered by the user like input parameters discussed in previous chapter. System will also use the database data for the calculation of sustainability indicators. To check the proposed computer aided system. The results of computer aided system are compared with the actual data measured in the industry.Two case studies are presented;first case study is of Electric iron sole plate made from Aluminium alloy (A307) by pressure die-casting process on 250 Ton capacity. The second case study is of electric reduce terminal is made from Aluminium alloy (A307) by pressure die-casting process on 350 ton capacity.

6.1 Case Study 1: Electric Iron Sole Plate

Electric iron sole plate is made from aluminium alloy (A307) by pressure die-casting process. The raw material for the electric iron sole plate is ingots of metal and no scrap raw material is used.
First of all Aluminium ingots is melted to about 720-750 ^{o}C in furnace oil fired reverberatory furnace. Flux is added to the molten metal which makes the impurities to float on metal surface in the form of slag and is collected and separated out.

After melting the molten metal is transferred to electric holding furnace using fork lifter. Which holds the molten metal at about 760-770 ^{0}C. Molten metal is then injected into the pressure die-casting machine under high pressure. After specific time the casting solidifies and taken out.

Results obtained from sustainability analyzer and shop floor for case study 1 are shown in table 2 and table 3 respectively.

Table 2: Pressure Die-Casting Process Analyzer Results

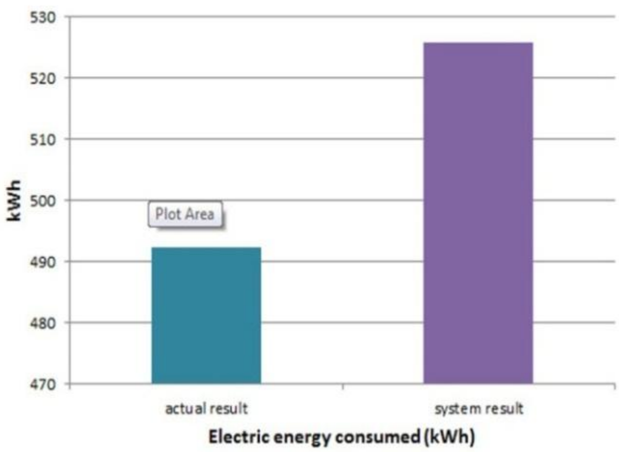
Sub Process	Electric energy consumed (kWh)	Flux consumed (Kg)	Solid Waste (Kg)	Die-coat lubricant (Liters)	Fuel consumed (Liters)
Melting	0	0.4	10	0	42.5
Holding	304	0	3.4	0	0
Pressure Die-casting	179.2	0	0.6	2.13	0
Macro-level activities	42.59	0	0	0	0.832
Total	525.76	0.4	14	2.13	43.34

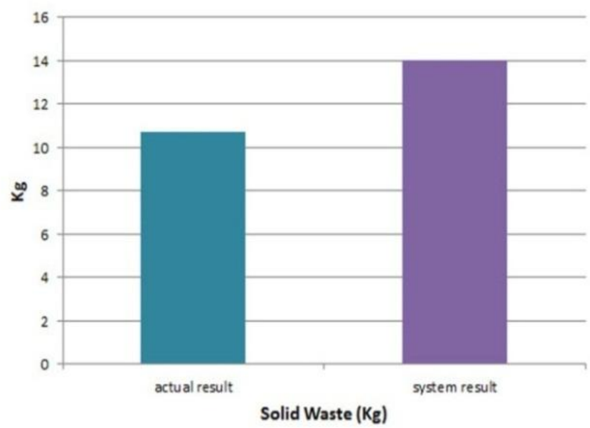
Table 3: Actual Results of Pressure Die-Casting Process measured from shop floor

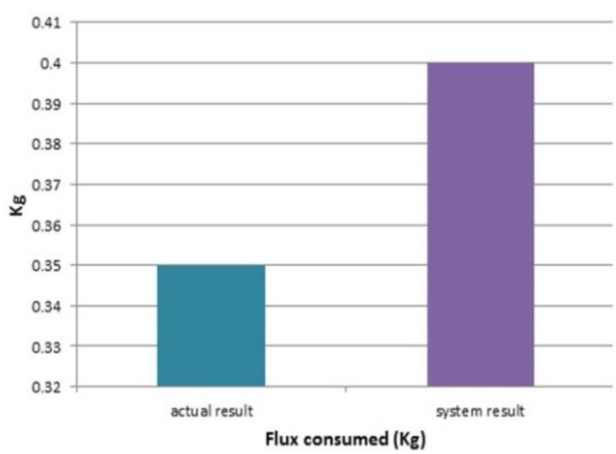
Sub Process	Electric energy consumed (kWh)	Flux consumed (Kg)	Solid Waste (Kg)	Die-coat lubricant (Liters)	Fuel consumed (Liters)
Melting	0	.350	7.5	0	51
Holding	300	0	2.75	0	0
Pressure Die-casting	152.8	0	.46	2	0
Macro-level activities	39.61	0	0	0	1.2
Total	492.41	.350	10.71	2	52.2

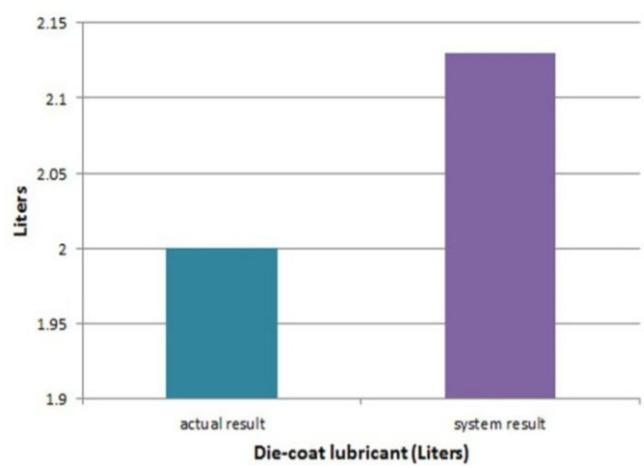
VII. COMPARISON OF ANALYZER DATA WITH SHOP FLOOR DATA

Results obtained from system analyzer and are compared with data measured from shop floor. The comparison of analyzer and shop floor data is shown with the help of graphs in figure 3. Electric energy consumption, the electric energy consumption calculated from actual measured data is less than system results. This variation is due to the system uses power rating to calculate the eclectic power consumption but in actual the machine operates below its power rating. The solid waste generation in actual is less than the system results this is because of the solid waste depends upon the type of raw material used if the raw material is ingots than the solid waste generation will be less as compare to if scrap is used as raw material. Flux consumption is less in actual practice than the system results this variation is due to the different types of flux is used in different companies so due to the variation in composition of the flux, flux consumption varies with small amount. Die-coat lubricant consumption is less in actual reading than the system results. This variation is due to the die-coat is applied manually on the die by spraying so the time of spraying the die-coat varies and with variation of time of spray the die-coat lubricant consumption also varies. Fuel consumption, the fuel consumption in actual is more than the system results. This variation is due to the heat energy loss.









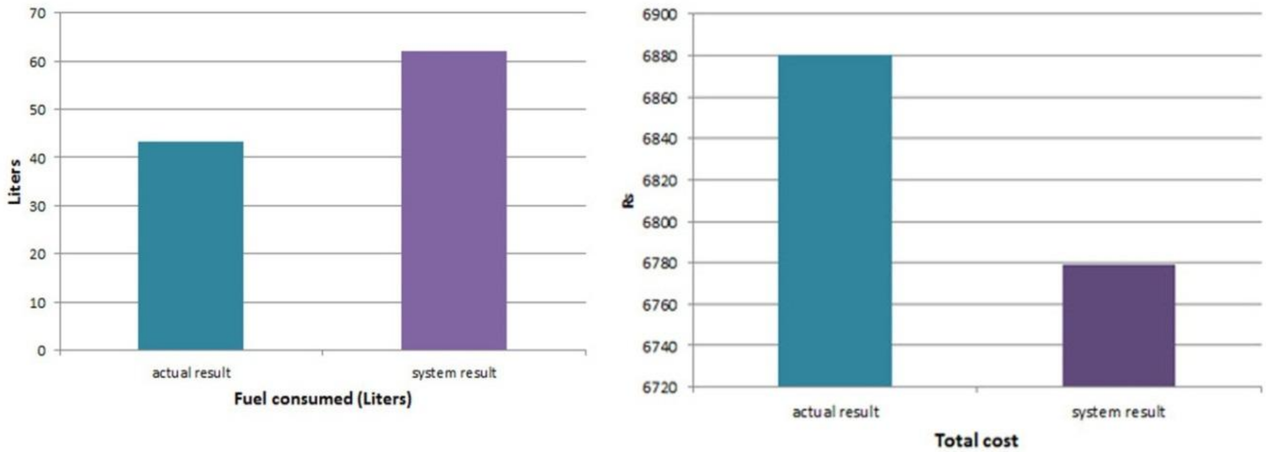


Figure 3: Comparisons of system and actual results

VIII. CONCLUSION

A computer aided Pressure die-casting process analyzer is presented in this work. The proposed system determines the sustainability indicators for pressure di-casting process. The proposed system uses sustainability indicators (energy use, solid waste, cost, and other misc. consumption like flux, die-coat lubricant and energy consumption for other micro-level activities like furnace blower, coolant pump, air compressor, fork lifter, fans and lights) and uses inbuilt database of die-casting process parameters. The user can interacts with system through user friendly GUI and prompts user to select the various choices in the system and enter data for the process plan. The system then process input data and retrieve required data from database and display the results in the form of indicators. The two case studies are presented for the comparison of system data with actual data measured in industry.

The proposed system can gives results for four indicators (energy use, solid waste, cost and misc. consumption in pressure die-casting process), in the future it can be extended to includes more sustainability indicators.

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