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Sustainable Modeling of Die-Casting Processes through Matlab

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Abstract

Manufacturing industries are facing tough competition due to increasing raw material cost and depleting natural resources. There is great pressure on the industry to produce environmental friendly products using environmental friendly processes. A computer-aided system named Sustainability Assessor for Die-casting has been developed and presented in this work. The system can assess the sustainability performance of a die casting process plan. The system determines the CO_2 emissions, solid waste, and energy use based on the process plan information. Two case studies for gravity die-casting and pressure die-casting are demonstrated the sustainability analysis based on system developed. The proposed system is verified by comparing results with the actual data measured from the shop floor. The developed system is beneficial for sustainability assessment comparing different plans alongside material properties, ultimately helping the die-casting industry to reduce the carbon emissions and material waste, besides improving energy efficiency. It is expected that this would be highly beneficial for determination of environmental impact of a process at early design stages. Therefore it would greatly help the manufacturing industry for selection of process plan based on sustainable indices. Overall impact of this study would have good impact on reducing air emissions and protecting environment.

Keywords: Die-Casting Process, Emission, Energy Consumption, Solid Wastage, Sustainability Manufacturing Analysis

1. Introduction

Nowadays, die-casting work piece is widely used in consumer electronic, vehicles, motorcycle, and computer. Die casting is a high-volume generation, which creates geometrically complex parts of nonferrous metals with incredible surface finishes and low piece rate. In die-casting production, the dust is subjected to overwhelming thermo mechanical loads. From the economic point of view, the cost of the castings is extremely important by the die service life. The melted metal is infused into the mold cavity under high pressures and speed in cavity filling, while in grease arrange, the anti-solder compounds and lubricants has been sprayed by the open die halves to bind mixes to guarantee the working die surface in a relatively low temperature range. As the flow velocities and temperature gradients are high, the severe conditions are mandated to achieve high-production rates. Due to vulnerable manufacturing processes, die casting impacts the environment, communities, natural resources and energy resources i.e. trades and workers etc. To attain the objectives of sustainable manufacturing, sustainability assessment have to achieve. Sustainability assessment is a technique, which considers producing related variables to present maintainability data consolidated, to compare parts made either utilizing manufacturing forms or similar manufacturing forms but another forms plans.

2. Motivation and Background

To take care of the demand, Die-casting industry would thrive in not so distant future. This would put extra weight

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on the environment and normal assets. In this manner, to address these issues die-casting enterprises are concentrating on sustainability measurement of die-casting process. The present strategies utilized for determination of sustainability for a product have following restrictions:

- Complex numerical relations are included.
- Manual computations should be utilized that are inclined to error.
- Lot of literature should be referred for gathering the information.
- At every stage, human effort is required.
- Is an iterative and tedious process.

Hence, it is felt that there is a requirement for a PC supported framework that could naturally decide maintainability for various processes arranges at the early plan organize and would be useful for industry. The framework would help in choosing more supportable process plans that would help in limiting use of non-renewable assets, picking energy efficient procedures, reducing waste and reduce carbon emissions. Researchers did a lot to extend die service life by different sustainability indicators and various methods have been proposed by them. Proposed the markers of supportable creation. These pointers are sorted into economic, social and ecological markers on the premise of accessible information and regularly measured aspects of generation like air emissions, waste, products, water consumption, energy use, materials use and many more[1]. In[2] performed an investigation for the impact of conventional die-casting on environment.

Distinguished energy and material utilized in die-casting and translated them into outflows and waste by items for the procedure. He achieved a life cycle analysis of sand throwing process from lichen preparation to the end product formation. The system considered the vapor waste, liquid waste and solid waste, produced during the sand casting process, for deciding the natural effect of the process using the concept of embodied energy[3]. An approach to define the influence of choice of machine on specific energy consumption. Energy consumption for electric injection, hybrid machines on the basis of specific energy consumption accounted by the proposed system[4]. Ecological effect of different manufacturing processes. When the environment is used as heat reservoir, whenever need energy to be used[5]. An approach for the assurance item related carbon emission from the electricity utilizes. Carbon emissions determination is constrained to assembling forms like turning, and open die forging[6]. Experimentally studied the variation of power consumption according to the design feature of a part[7]. A new methodology for computing Carbon Weight (CW) in fabricating process from part level to assembly level[8]. A tool to evaluate materials and assembling energy in view of the bill of material for an item. Proposed tool mechanism determines the energy evaluate by compiling accessible data from material embodied figures, exact and bill of material. This tool takes detailed bill of material as response and records energy evaluate. But for the same part energy requirement can be different according to the process plan and this idea has not been taken into consideration[9]. A structure for quantitative estimation of sustainability is in a manufacturing system. It includes indicators buffer, measurement process, and performance evolution on the basis of bottom line. In addition to financial performance, bottom lines take into social performance and account ecological. Carbon emission and energy utilize markers are taken into consideration. Manageability estimation is restricted to machining operations[10].

3. Die-Casting Process

Die-casting is one of the close net shapes producing process used to frame complex shapes with high dimensional exactly and a good surface complete in a short period of time. The die-casting procedure can be partitioned into these steps:

- **Preparing the metal** – removing dirt, dampness. Charge material like piece metal, ingots is preheated in a fossil fuel fired furnace.
- **Melting the metal** – energy is supplied from combustion of fossil fuels, electricity to raise the metal temperature above its melting point to pouring temperature.
- **Refining and treating molten metal –** elements or materials are introduced to refine the charge material
- **Holding molten metal**- melted metal is maintained in melted
- **Tapping molten metal** – transmitting the melted metal from the furnace to transport ladle
- **Transporting molten metal –** moving the molten metal to the point of use by transportation vehicles

- **Die-casting –** poring molten metal into a permanent mold and holding it till solidification. The mold made in to two halves opens and casting is removed. The steps discussed above are illustrated in Figure 1.

Die-casting processes can be classified into three types.

- Gravity die-casting.
- In gravity die-casting lichen metal is discharged from a vessel into the lichen without application of any external pressure other than gravity. The solid casting is ejected out of lichen and the lichen is cleaned for the next cycle.
- Low Pressure Die-Casting

A metal lichen or die is attached above a sealed furnace that has the melted metal. A riser tube is a tube which is used to combines the base of the die to the melted metal bath. The chamber having the melted metal that is pressurized inside a scope of 20-100 kPa and the metal is forced up into the lichen. Once the casting has solidified, the pressure is discharged and the melted metal falls back into the bath.

- High Pressure Die-Casting Process

A permanent lichen or die, made up of several parts has liquid metal injected into it, using a hydraulic piston, at

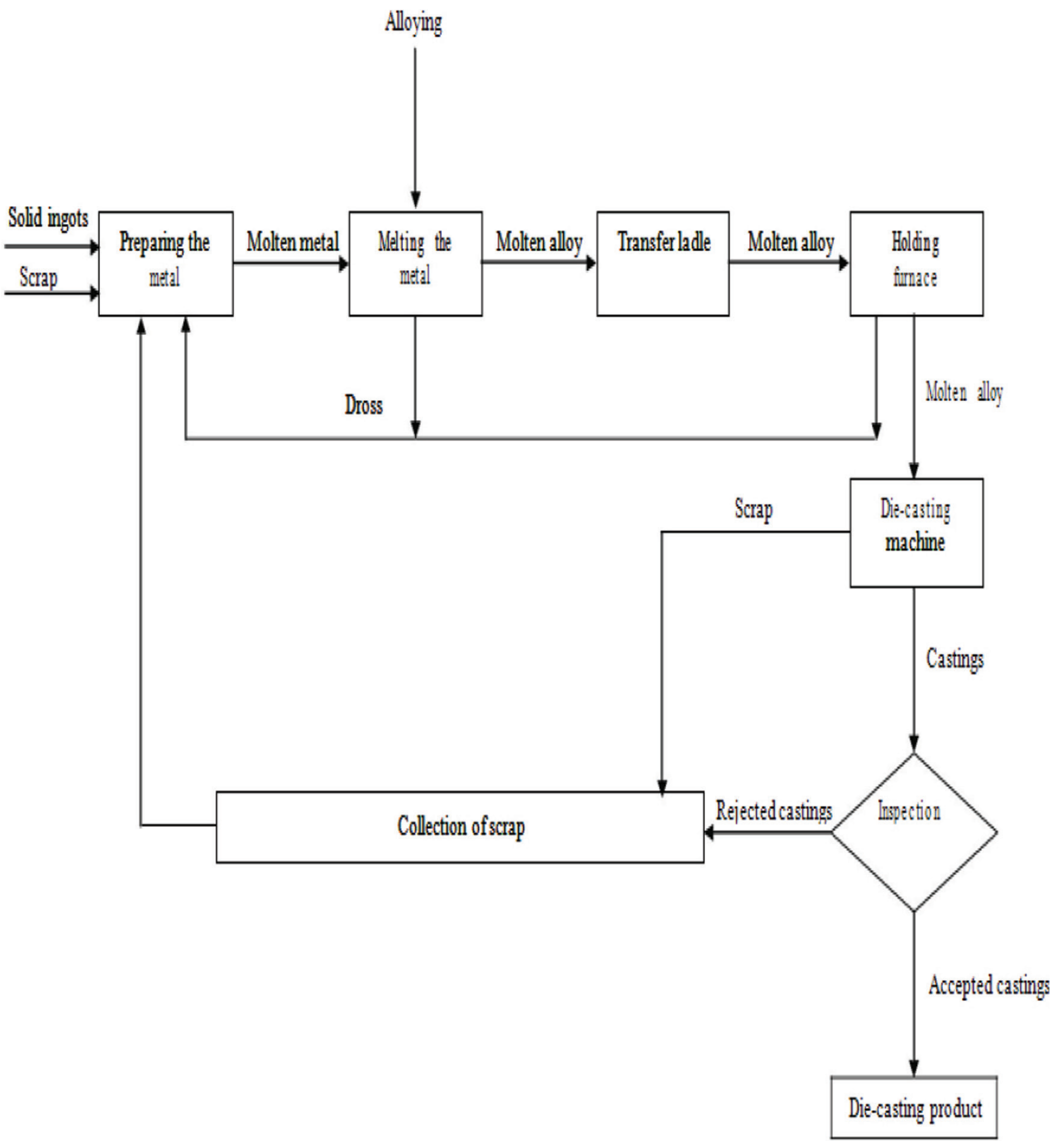

Figure 1. Die casting process.

pressures typically between 20 and 100MPa, depending on the alloy. The lichen absorbs dissipates the heat, stresses of injection, and ejects the casting before resetting for the next casting[10].

4. Indicators of Sustainable Production in Die Casting

Indicators for sustainable production are classified into the following:

- Social indicators – focus on the labor opportunities and society ethical values.
- Economic indicators – focus on the financial impact of sustainable development.
- Environmental indicators – focus on the environmental impacts due to production.

The Figure 2 represents the indicators for sustainable production. There are number of different types of sustainability indicators but Presented work focused on three most effective Indicators.

4.1 Energy Use Indicator

Die-casting is a cost driven process. Profit margins are eroding rapidly due to rising energy prices. Moreover competition in the market has created pressure on the die casters to reduce product cost. Therefore for selecting most energy efficient process plan energy use indicator is taken into consideration.

4.2 Air Emission Indicator

Use of electric energy and fossil fuels are responsible for carbon dioxide emissions. In near future, it is assumed that assembling enterprises need to pay discharge charges. These charges would put additional weight on die casting industries and cut the benefits. In this manner, air emissions indicator is selected that measures the discharges radiated amid the procedure. This would further help in selecting a sustainable process plan for the given product.

4.3 Solid Waste Indicator

Solid waste comprises of dross and scrap which is generated during die-casting process. This solid waste has to

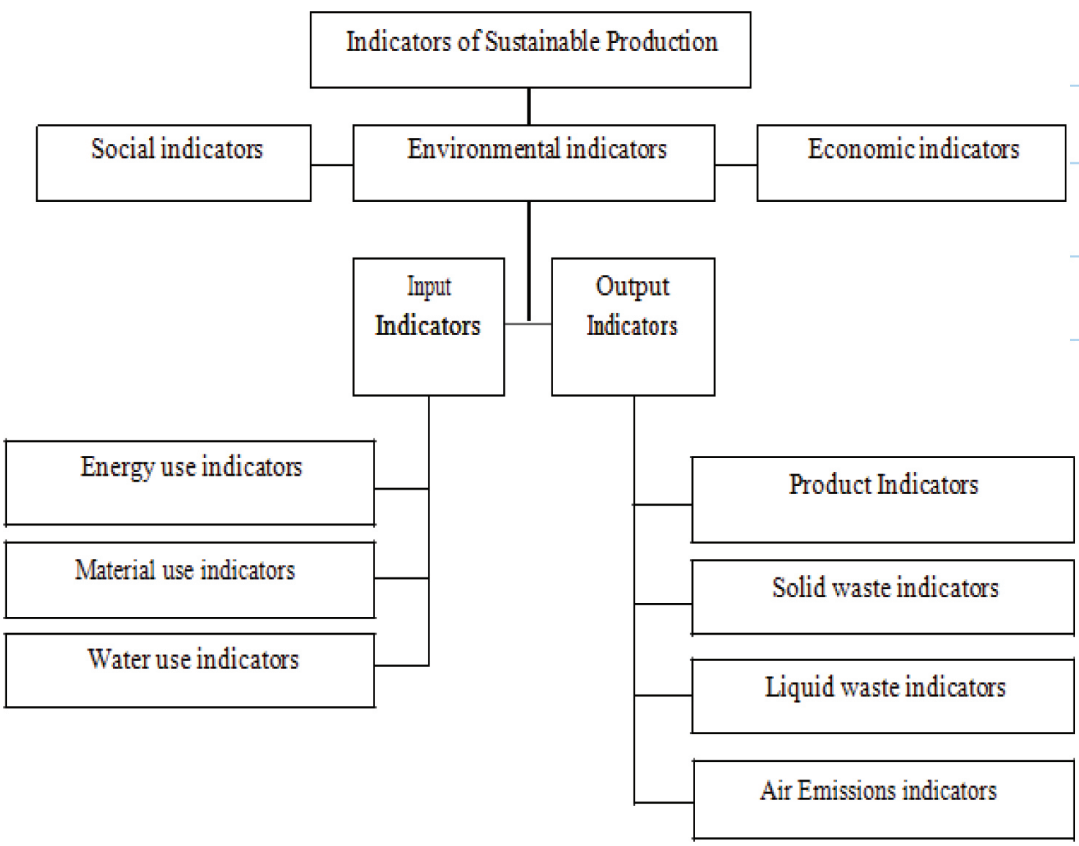

Figure 2. Indicators for sustainable production[6].

be recollected and melted. This collection and re-melting of the waste requires energy and transportation which increases the cost of the product. So process plan for die-casting product should be selected with minimal generation of solid waste. Due to this reasons solid waste is taken as an indicator for sustainability analysis. The process flow diagrams for Gravity die–casting is represented in Figure 3 and pressure die-casting indicators is represented in Figure 4.

5. Sustainability Analyzer

The proposed system uses knowledge-base of die-casting process. Die-casting process knowledge in terms of melting temperatures, mass of charge, furnace parameters, machine power profiles, casting size, shot weight etc. The Table 1 represents material and alloy database. System utilizes coded empirical relations, user input and database for the determination of sustainability indicators. Sustainability analyzer algorithm is divided into three modules namely, input module, processing module and result and, report generation module. The different databases used for this analyzer are described in Table 2.

Database shown in Table 3 is known as furnace database. Furnace database consist of various furnaces like pre-melting fossil fuel fired furnaces, induction furnaces and crucible furnace. Values of constant parameters like power profile, maximum charging capacity, and furnace type and furnace name have been shown in the furnace database.

Die-casting machine database consist of machine type, machine name and power profile of the machines. Die-casting machine database have been illustrated in the Table 4. Miscellaneous activities like lighting load, load of each work section and fork lifters load are stored in to the miscellaneous database. System input and output parameters for the different sub-processes have been discussed into the following paragraphs.

5.1 System Input and Output Parameters

On the basis of study various variable parameters are identified. Therefore, in the system these parameters are user defined which gives output in the form of sustainability indicators such as energy consumption, carbon emissions and solid waste, as shown in Table 5.

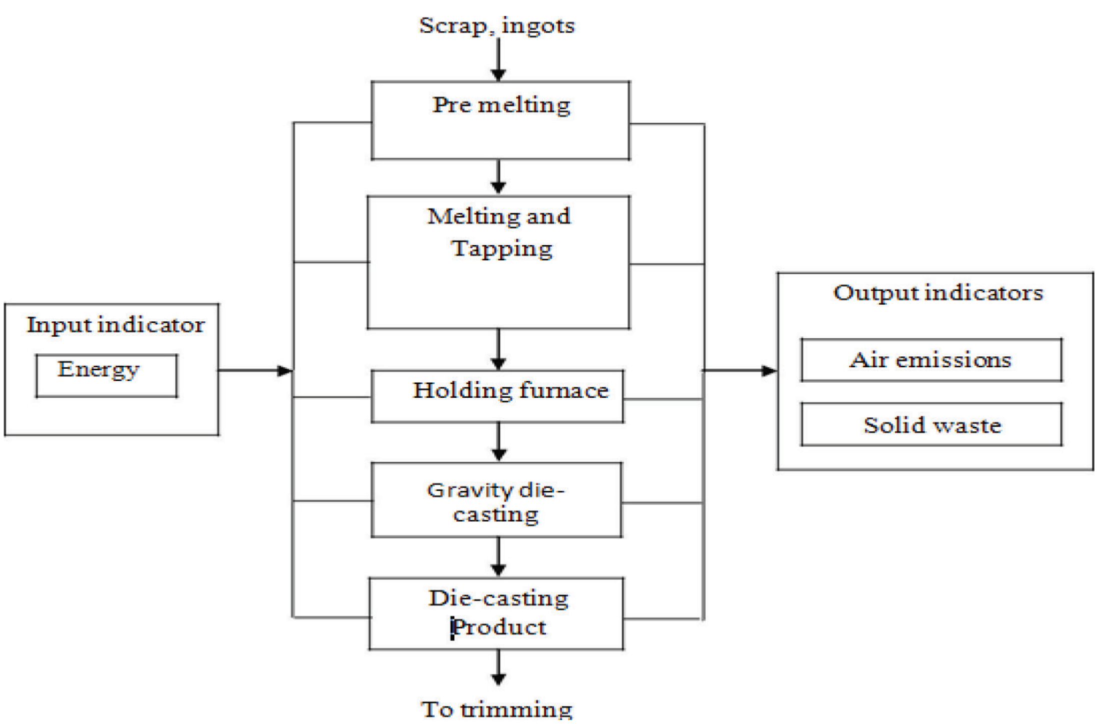

Figure 3. Process flow diagram for gravity die-casting process with input and output indicators.

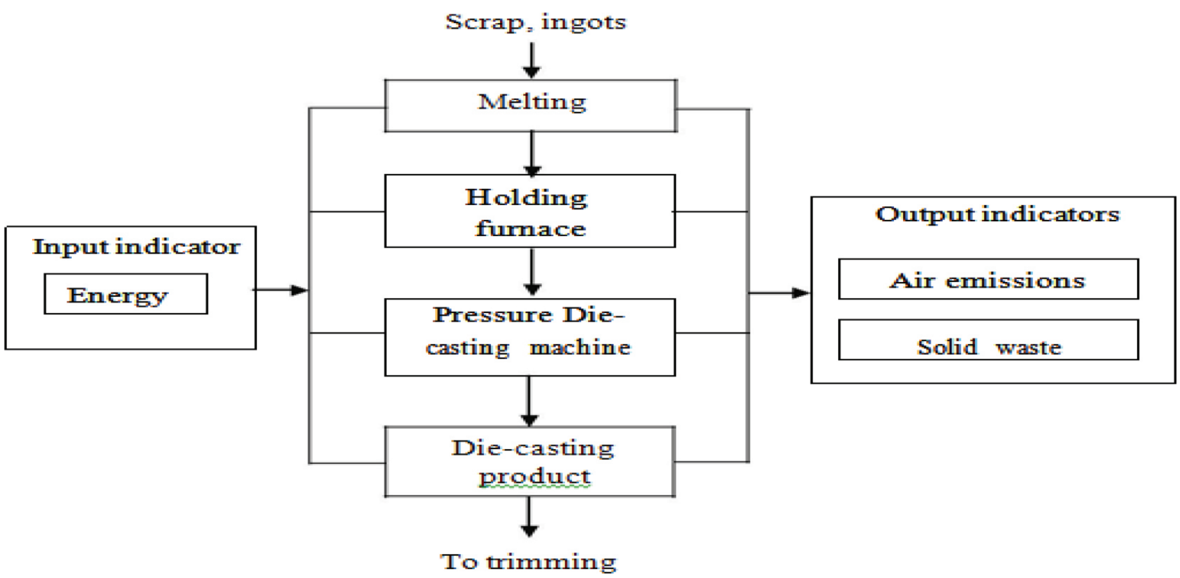

Figure 4. Process flow diagram for pressure die-casting process with input and output indicators.

Table 1. Material and alloy database

Material	Alloy	Latent heat of Fusion (KJ/Kg)	Specific heat (KJ/Kg K)	Solid Temp. (°C)	Liquid Temp. (°C)
Alumi-num	AC8A	389	0.963	530	570
Zinc	Z5	110	0.39	376	400

Table 2. Process plan database

S. No.	Process	Sub- S. No processes
1.	Gravity die-casting	Pre-melting in oil fired furnace Melting and tapping in induction furnace Holding furnace Gravity die-casting machine Miscellaneous activities
2.	Pressure die-casting	Melting and holding in a gas fired furnace Pressure die-casting machine

5.2 Sustainability Analyzer Results for the Gravity Die-Casting

On the basis of this data, sustainability analyzer determines sustainability indices like carbon emissions, energy consumption and solid waste for gravity die-casting process. The sustainability analysis is performed per shift basis. Results of sustainability analyzer for the gravity die-casting process have been shown into the Table 6. Results are displayed into the result panel of the sustainability analyzer. Sustainability indicators i.e., carbon emissions, electrical energy, energy from the fuel and solid waste for gravity die-casting process have been determined by the proposed system.

To make the proposed system useful as a tool for sustainability analysis, a graphical output panel has been developed which primarily gives a display of the sustainability indices. Results in the graphical format for the gravity die-casting process have been shown in Figure 5. First bar of the bar chart of sustainability indices represents CO_2 emissions occurred during the gravity die-casting process. Second and third bar indicate the energy recycled in the form of electrical and fossil fuel

Table 3. Furnace database

S. No.	Furnace name	Furnace type	Charge Capacity(Kg)	Power load (KWh)
Pre-melting furnace database				
1.	Reverberatory (SK1)	Diesel	800	7.00
2.	Reverberatory (SK2)	Diesel	600	5.20
3.	Reverberatory (V.AGNI OLD)	Diesel	1000	11.40
4.	Reverberatory (V.AGNI NEW)	Diesel	1200	29.50
Induction furnace database				
1.	Megatherm	Electrical	1000	600
2.	Piller	Electrical	1000	400
3.	Junker	Electrical	1200	266
Holding furnace database				
1.	HF 1	Electrical	300	28
2.	HF 2	Electrical	500	38
3.	Thermo-tech	Gas fired	500	1.5 (blower)

Table 4. Die-casting machine database

S. No	Machine name	Machine Type	Power load (KWh)
1.	DCM 7	Gravity die-casting	3.89
2.	DCM 19	Gravity die-casting	4.28
3.	PDCM300	Pressure die-casting	25.72

energy respectively. The fourth bar represents the solid waste produced during the gravity die-casting process. The proposed system utilizes theoretical formulae for the determination of sustainability indices. Therefore, to check the accurateness of sustainability analyzer, system results have been compared with the actual measured data. Comparison of the results reveals that the carbon

Table 5. Input and output parameters of sustainability analyzer

S. No.	Sub-processes of die-Casting	Inputs parameters	Output parameters
1.	Metal Melting	Furnace parameters Mass of charge Melting time for the cycle Furnace efficiency Ambient temperature Final temperature	Total Energy consumption Carbon-emissions Solid waste
2.	Metal holding	Furnace parameters Auxiliary equipment's used Mass of charge Number of holding furnaces per cell Holding time Furnace efficiency	
3.	Die-casting (gravity or pressure die-casting)	Die-casting process Shot weight Cycle time for machine Cell number machine in use Number and type of holding furnace in a cell	
4.	Miscellaneous activities	Transportation work cell	Total Energy consumption Carbon-emissions

Table 6. Results for the gravity die-casting process

Sub-processes	Carbon emission KgCO2	Electrical energy Consumed (KWh)	Fuel consumed (lt.)	Solid waste (Kg)
Pre-melting in oil fired furnace	988.761	53.20	358.96	176
Melting and tapping in induction furnace	2166.800	2605.71	0	10.971
Holding furnace	376.656	448.40	0	6.0
Die-casting machine	109.447	130.294	0	0.622
Micro-level activities	138.303	164.646	0	0
Total	3601.97	3402.25	358.96	193.59

weight from calculation by the system is 4% more than results obtained by actual measurements. The difference is represented with the help of Figure 6. This deviation is due to consideration of rated power of machines in calculating the carbon weight for electricity consumption. System estimated energy consumption is 6.5% more than actual one. This difference is because of the reason that the system utilizes rated power for the determination of energy consumption but practically machines operate below the rated value of power. Fossil fuel consumption, which has been calculated from the actual measured data, is slightly more than the system results. This variation in actual and system result is due to energy losses. These energy losses cannot be considered in theoretical calculations. Therefore, actual result is 3.9% more than that calculated by the system.

Solid waste determination reveals an inaccuracy of mere 6.9%. In actual practice the solid waste generation was more as compared to theoretical one. It can vary from company to company. Therefore proposed system gives approximately fine results

5.3 Sustainability Analyzer Results for the Pressure Die-Casting

System determines sustainability indices like carbon emissions, electrical energy required, fuel required and solid waste from the input parameters delivered by the user. The sustainability analysis is performed per shift basis. Results of sustainability analyzer for the pressure die-casting process have been shown in the Table 7.

Sustainability indicators i.e., carbon emissions, electrical energy, energy from the fuel and solid waste for pressure die-casting process have been determined by the proposed system. Graphical result for the pressure die-casting process has been shown in Figure 7. First bar of the bar chart of sustainability indices represents CO2 emissions during the pressure die-casting process. Second and third bar indicate the energy used in the form

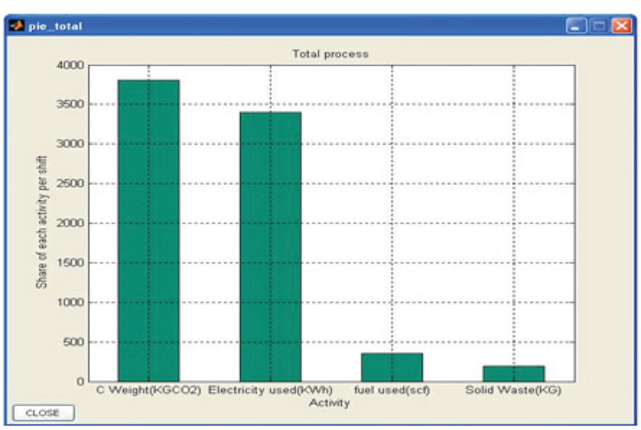

Figure 5. Sustainability indicators for the gravity die-casting process.

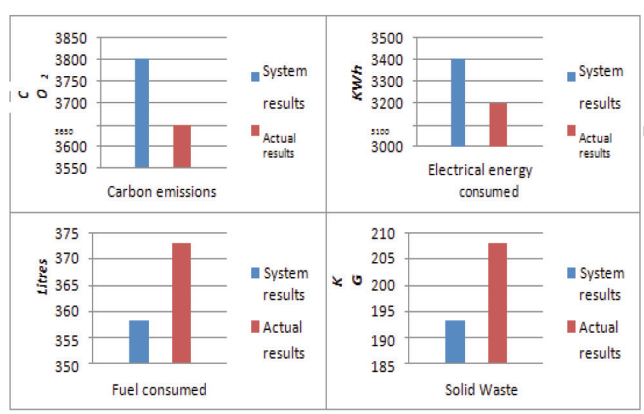

Figure 6. Comparison of system results with the actual measured industrial data.

Table 7. Results for the pressure die-casting process

Sub-processes	Carbon emission KGCO2	Electrical energy consumed (KWh)	Fuel consumed (lt.)	Solid waste (KG)
Melting and holding furnace	36.046	10.6	530.699	22.5
Pressure Die-casting machine	152.039	180.99	0	.560
Micro-level activities	6.10	7.64	0	0
Total	196.19	199.44	530.699	23.06

of electrical and fossil fuel energy respectively. The fourth bar represents the solid waste produced during the pressure die-casting process.

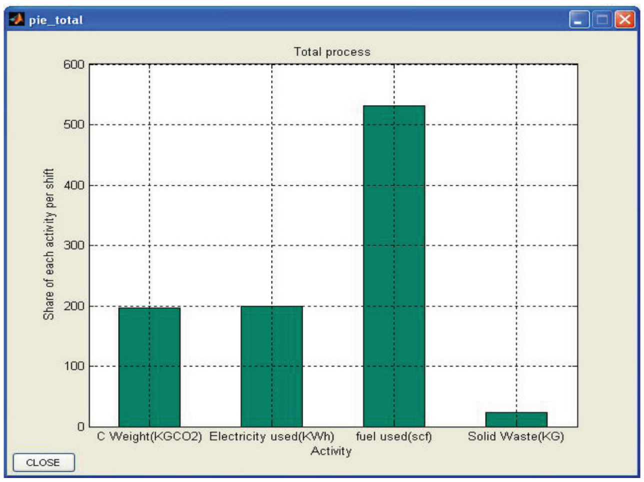

Figure 7. Sustainability indicators for pressure die-casting process.

From the results company management can analyze and can take steps to improve present sustainable state for the pressure die-casting process. Theoretical formulae have been utilized for the determination of sustainability indices. Therefore, to check the exactness of sustainability analyzer system results have been compared with the definite results. Comparison of the sustainability indices determined for pressure die-casting process using sustainability analyzer has been illustrated in Figure 8. From figure it is seen that there is difference of 5.6% in carbon weight index values obtained from the system and that calculated on behalf of actual measurement of the process parameters. This difference in carbon weight index is due to the reason that the value of assumed efficiency is less than that obtained by actual measurements. This disparity in values of actual and efficiency also results in difference in fuel use which is 4.6% more in case of fuel use determined by the system. In pressure die-casting process, taken for the study, electrical energy is used for operating machines and miscellaneous activities. The electric energy use calculated from the system is 6.0% more than that calculated by actual measurement of process parameters. At last solid waste generation determined by actual

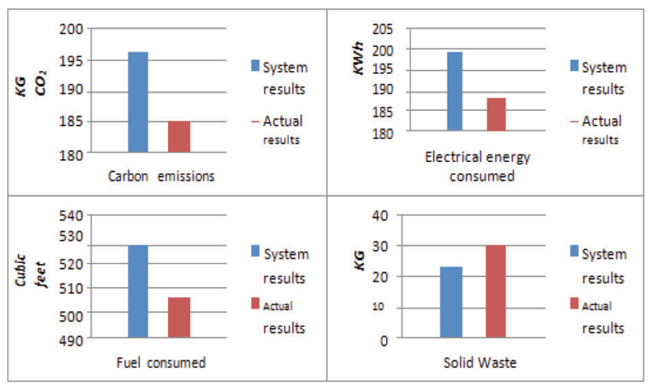

Figure 8. Comparison of system results with the actual industrial data.

Measurement is 2.5% more as compared to that calculated by the system. Waste generation depends on the company production process.

6. Conclusion

In this work, determination of sustainability of die-casting process has been presented that is based on computer aided system. For two die-casting processes, the system is designed: pressure and gravity die-casting. By using strong database of the process parameters of die-casting process, the system is built. The sustainability of die-casting is measured in terms of sustainability indices. The sustainability indices used in this work are air emissions, energy use and solid waste. The system prompts the operator to enter the input or choose the value of process parameters. Interaction between the system and user is according the process plan of the product. The proposed system processes the input and gives the output in form of sustainability indices for the process plan of the part. Present system is able to quantify sustainability in terms of sustainability indices. By the system, the sustainability indices are determined that are close to that calculated on the basis of actual measurements of process parameters. Validity and usage of determination of sustainability indices from process plan of a part is shown in this proposed system. The system can also be used to compare two process plans for manufacturing a part and selecting the one with higher sustainability.

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