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A COMPUTER-AIDED SYSTEM FOR SUSTAINABILITY ANALYSIS FOR THE DIE-CASTING PROCESS

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ABSTRACT

Currently available sustainability analysis systems for the die-casting process primarily depend on the material properties and do not account for process information. As a result they are unable to assess or compare the sustainability of parts made using different process plans. In this paper, we propose a new computer-aided system named *Sustainability Analyzer for Die-casting Process*. Here, we discuss the details of the architecture and the working of the proposed system. We analyze sustainability using three sustainability indicators, namely energy use, solid waste and carbon emissions. The proposed system is verified by comparing results with the actual data measured from the shop floor. The proposed system is beneficial for sustainability analysis comparing different plans alongside material properties, ultimately helping the die-casting industry to reduce carbon emissions and material waste besides improving energy efficiency.

Keywords: Die-casting, process planning, sustainable manufacturing, sustainability indicator, sustainability analysis

INTRODUCTION

The Department of Commerce [1] defines sustainable manufacturing as, '*the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound*'.

To achieve the objectives of sustainable manufacturing, sustainability analysis needs to be performed. Sustainability analysis is a procedure which considers manufacturing related factors to present sustainability information in a consolidated way for comparing parts made either using different manufacturing processes or the same manufacturing process but different process plans.

Sustainability of a manufactured part is represented using sustainability indicators. The benefit of using these indicators is that they compress large data of manufacturing process information into a format that is easier to understand, compare and comprehend. A number of indicators are available for sustainable manufacturing and broadly classified into social, economic and environmental indicators [2]. Companies use these indicators to set targets and monitor progress in sustainable manufacturing. A survey of the corporate sustainability reports demonstrated that environmental and social impact assessment have received less attention as a whole to evaluate sustainability of a manufacturing process [3]. Furthermore, comparison and analysis of production systems demands quantitative measures for sustainability. Such quantitative measurement requires environmental indicators. For simplicity, environmental indicators are classified into input and output indicators [2]. Input indicators for sustainability include energy use, material use and water use indicators. Output indicators include product, solid waste, liquid waste and air emissions indicators. These indicators are shown in Figure 1.

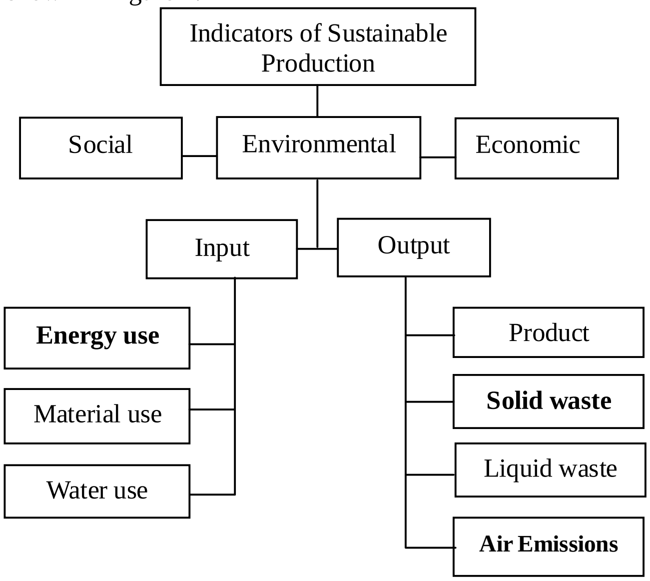

Figure 1 Indicators for sustainable production [2]

This work focuses on the sustainability analysis for the die-casting process by using three sustainability indicators, namely energy use, air emission and solid waste. The reasons for selecting these indicators follow.

- The die-casting process is inherently an energy consuming process. Hence, *Energy Use* is chosen as one of the indicators in this study.
- One way of improving material efficiency in the die-casting process is to prevent or reduce wastage of the material. Solid waste and liquid waste are the indicators, which represent material wastage. Major contributors of material waste in the die-casting process are scrap and dross. Both scrap and dross are in the form of solid waste, which affects yield of the die-casting process. Therefore, *Solid Waste Indicator* is selected as one indicator in this study.
- Further, the use of electric energy and fossil fuels results in carbon dioxide emissions. In the near future, it is expected that manufacturing industries will have to pay emission taxes [4]. These taxes would put an extra burden on die-casting industries thereby further reducing the profits. Therefore, *Air Emission Indicator*, which quantifies the emissions during the process, is selected as one of the criterion.

Carbon emission, which is a form of *Air Emission Indicator* is closely linked to the electrical energy and fossil fuels consumed. Information about carbon emissions is useful to directly compare different process plans in which quantities of fuel and electricity may differ. Quantifying carbon emission in such cases provides a common metric for comparison. Some of the other indicators namely material use, water use and liquid waste also affect cost yet have not been considered within the scope of this study.

Present software tools available in the industry fall short for sustainability analysis when differentiating two different process plans for a part. Industries use LCI (Life Cycle Inventory) based tools, among other tools, to determine the sustainability impact of a particular product. Major limitations with the use of LCI databases, is the dependence on the bill of material (BOM) of the product and the details up-to the level of the unit manufacturing process are not included [5,6]. Gutowski *et al.* [7] also suggested that the specific energy requirements for manufacturing processes are not constant as many life cycle analysis tools assume. Following are the major limitations to compare and assess sustainability of two manufacturing process plans for die-casting if it:

- involves complex mathematical relations
- involves manual calculations that are prone to error
- involves lots of literature search for data collection
- involves human effort at almost every stage
- involves iterative and time-consuming processes
- lacks standardized LCI databases related to manufacturing

With the above limitations, we identified a need for developing a computer-aided system that could automatically determine sustainability for different process plans. Such a system should support sustainability assessments at early stages of process planning. This would help the die-casting industry to reduce emissions and waste, besides improving energy efficiency.

In this paper, we propose a system named the *Sustainability Analyzer for Die-casting Process.* This system is focused on two types of die-casting processes; gravity die-casting and pressure die-casting [8]. The proposed system can subsequently be expanded to a complete solution for sustainability analysis for other major manufacturing processes.

The rest of the paper is organized into five sections. The related work section presents a brief literature review followed by the section on the determination of sustainability indicators for the die-casting process. Subsequent sections discuss determination of sustainability indicators from actual shop floor information, system architecture, implementation and results. Finally, we present conclusions and future work.

NOMENCLATURE

E	Energy consumed (kWh)
P_{rated}	Rated power of machine (kW)
H_s	Calorific value
ρ	Density of fuel (kg/m^3)
t	Time (hr)
cos φ	Power factor
CW	Carbon emissions (kg of CO_2)
f	Emission factor (kg of CO_2/kWh)
I	Line current (A)
M	Mass of alloy (kg)
Q_{total}	Total heat required to super-heat casting alloy (MJ/kg)

QF	Quantity of fuel consumed (m^3)
V	Line voltage (kV)
η	Efficiency
$W_{molten\ metal}$	Mass of molten metal (kg)
$W_{\%\ of\ melt\ loss}$	Percentage of mass waste (kg)

RELATED WORK

Previous work related to sustainability analysis of manufacturing processes is discussed in this section. Krajnc and Glavič [8] developed a methodology for measuring sustainability indicators and a strategic set of metrics for assessing the sustainability level of a company. The choice of the sustainability indicator for a company is left to the user. However, the developed methodology was not demonstrated on any manufacturing process. Dalquist and Gutowski [10] performed an analysis to find the impact of conventional die-casting on the environment. Environmental footprints were determined by using qualitative assessment of substance flows in the die-casting process. Energy and material used in die-casting was determined and interpreted into emissions and waste for a product to be made by die-casting. Thiriez and Gutowski [11] presented a methodology to determine the impact of machine selection on specific energy consumption. Environmental performance of different machines was accounted on the basis of energy related emissions. It also provided a life cycle inventory identifying major sources of emissions in the injection molding process. Dalquist and Gutowski [12] performed a life cycle analysis of the sand casting process from mold preparation to the final product formation. They considered vapor waste, aqueous waste, and solid waste generated during the sand casting process for determining the environmental impact of the process using the concept of embodied energy. Gutowski *et al.* [7] studied environmental impact of different manufacturing processes. Environmental impact was accounted for with the help of exergy used during the manufacturing process. Exergy is defined as the potential of a system to cause change as it achieves equilibrium with its environment. Jeswiet and Kara [2] proposed a method that connects the electrical energy used in manufacturing directly to the carbon emissions created using the electrical energy. The developed methodology was implemented on machining operations like turning and milling. Taha *et al.* [13] presented a methodology that links design features of a product to the environmental impact. Behavior of power consumption is studied with the change in design features of a product. Specific energy consumption for the turning operation was determined experimentally and interpreted into CO_2 emissions. Ameta *et al.* [14] developed a methodology for computing carbon weight (CW) in the manufacturing process from part level to assembly level. A methodology of tolerance allocation and redesign is applied to optimize the design. Ciceri *et al.* [15] proposed a system to estimate materials and energy requirements for manufacturing based on the bill of material for a product. The system determines the energy estimate by compiling available data from bill of materials. Feng and Juong [16] proposed a framework for quantitative measurement of sustainability for machining operations. In their study, carbon emission and energy use indicators are taken into consideration.

Literature review suggests that only limited research has been done for sustainability analysis for the die-casting industry. Most of the reported research was focused on the macro level and there are no tools to analyze sustainability of a product made using different process plans. Moreover, some studies focused on how to manufacture environmental friendly castings [7, 8] but do not specifically assess the sustainability of the process. Based on the reviewed literature, we observed that research attempts to automate the determination of sustainability indicators from the process information are almost negligible.

The aim of this paper is to propose a system for sustainability analysis of a part made by using the die-casting process. The *Sustainability Analyzer for Die-casting Process* system can be used as a software tool to perform sustainability analysis for the die-casting process at early stages of process planning. As mentioned previously the focus of the proposed system is on two types of die-casting processes: Gravity die-casting and Pressure die-casting [8].

The subsequent sections provide details of the methodology adopted in the proposed system.

DETERMINATION OF SUSTAINABILITY INDICATORS

To determine sustainability indicators for the die-casting process, inputs and outputs of material and energy at various stages of the die-casting process need to be determined. Furthermore, the die-casting process involves inputs and outputs of materials and energy resources at various stages (also called sub-processes) and in various forms. Detailed input and output flow of materials and energy for a typical die-casting is shown in Figure 2. This process flow is used in the proposed system to identify sustainability indicators, i.e., energy use, solid waste and air emission.

The operation of the die-casting process is as follows. First, die-casting alloy in solid form is fed into the main breakdown furnace, where the material is brought to the molten stage and refined. Inputs to this furnace are diesel or natural gas, electricity, flux, degassing agents and demagging agents. Refined alloy obtained from breakdown furnace is then transferred to the next stage of the process, i.e., ladle to the monorail delivery system. Subsequent stages of the die-casting process are die-casting furnace and die-casting machines.

At various stages of the die-casting process, there is certain material waste and energy consumption, which needs to be determined to determine energy use, solid waste and air emission indicators. Methodology to determine the three sustainability indicators, namely *Energy Use, Air Emission and Solid Waste* is discussed in the following paragraphs.

Energy use indicator

In the die-casting process two types of energy sources are used, i.e., electrical energy, and heat energy from fossil fuels such as diesel and natural gas. Electrical energy and fuel consumption in the die-casting process can be determined by using science-based methods which are available in the literature [18, 19]. These methods are discussed in the following sub-sections.

Electrical Energy Consumed

In die-casting, electric energy is consumed for activities like melting the metal, holding the molten metal and casting of the part. The total electrical energy consumed depends on cycle time and rated power load characteristics of the machine. Therefore electrical energy consumed can be estimated by using the following relationship [18].

$$E = P_{rated} \times t \quad (1)$$

It is assumed that electrical energy consumption per unit time on the machines used is constant for an eight-hour shift. The amount of electrical energy consumed by different machines is reported in kilowatt-hours (kWh).

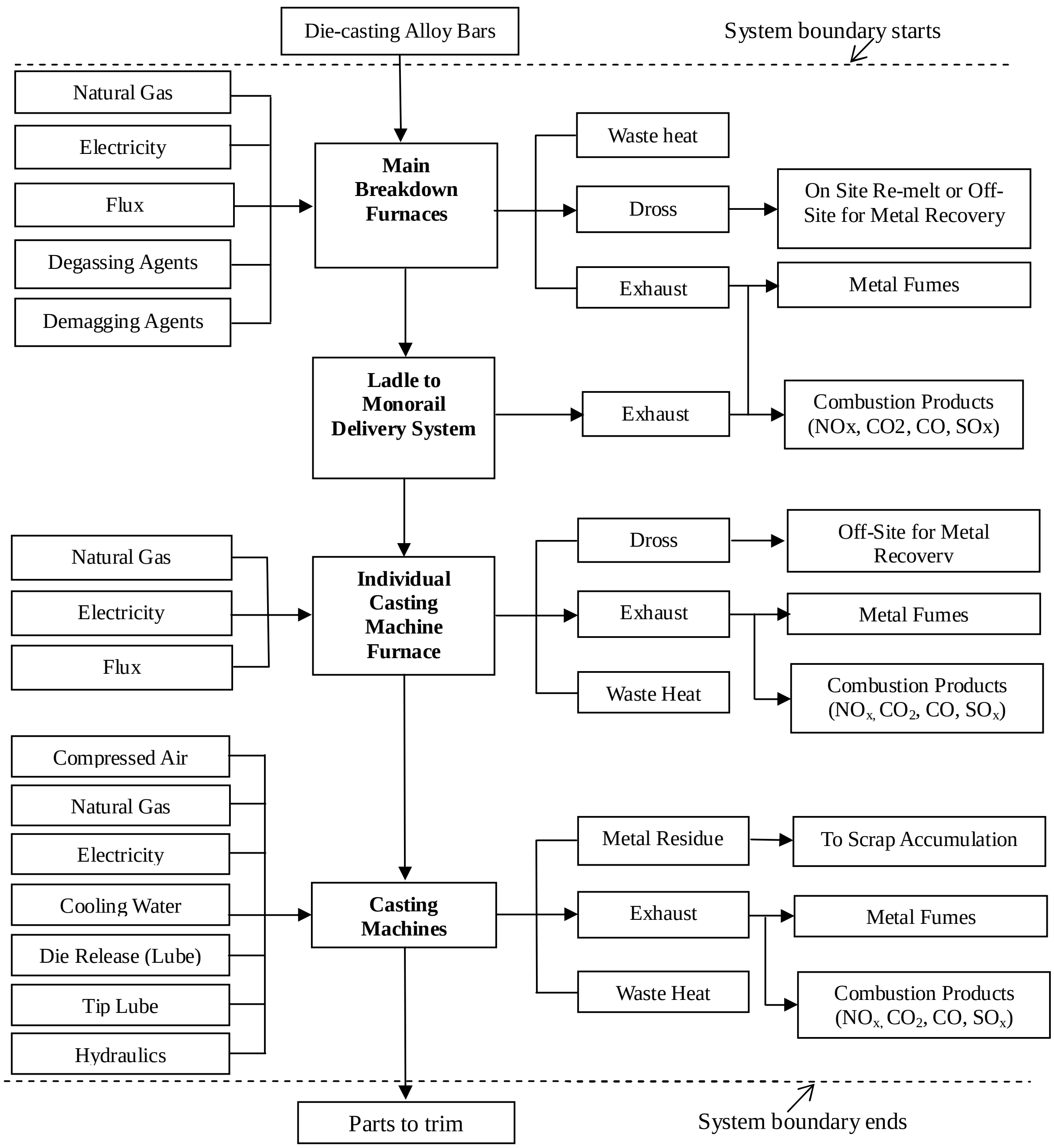

Figure 2 Flow diagram for a typical die-casting process [17]

Quantity of Fuel Consumed

Quantity of fuel consumed for melting the metal depends upon heat required for bringing the solid metal to the injection temperature. This heat is required at three stages:

i. Heat energy for raising the temperature of casting alloy from ambient to solidus temperature (Q_s)

ii. Heat energy required to raise the temperature from solidus to liquidous temperature (Q_f)

iii. Heat energy required to superheat casting alloy (Q_{sh})

Therefore, total heat energy can be given by using the following equation [19].

$$Q_{total} = Q_s + Q_f + Q_{sh} \quad (2)$$

Note that the quantity of fuel used depends on the alloy properties, ambient temperature, fuel properties, efficiency of furnaces, alloy quantity and required temperature of superheating the alloy. The following relationship is used to determine quantity of the fuel required.

$$QF = \frac{Q_{total}}{\eta \times H_s \times \rho} \quad (3)$$

Air Emission Indicator

Air emission indicator refers to the CO_2 emissions during the die-casting process. CO_2 emissions are caused directly by the onsite combustion of fuel and indirectly by the use of electricity within the company [20]. Emissions can be classified into electric energy emissions and fossil fuel-related emissions and can be quantified in terms of carbon weight [21]. The method of calculating the air emission indicator is subsequently discussed.

Air Emissions due to Electric Energy Usage

Air emissions due to electric energy depend upon the amount of electrical energy consumed. The method to find consumption of electrical energy was discussed in the previous section. Carbon emissions for electric energy used can be determined by using the following relationship.

$$CW = E \times f \quad (4)$$

Where, f is the emission factor and depends upon the sources of electric energy generation namely nuclear, coal, and hydro. Value of this emission factor is taken from the CO_2 database for the Indian power sector provided by Central Electricity Authority [22].

Air Emissions due to Fossil Fuel Usage

Air emissions related to the use of fossil fuel can be determined from the quantity of fuel burnt during melting and holding of the die-casting alloy. Quantity of fuel required for melting can be calculated from equations 2 and 3. The carbon weight due to fossil fuel consumed can be determined by using the following equation.

$$CW = QF \times f \quad (5)$$

According to Department of Environment Food and Rural Affairs and US Environmental Protection Agency, emission factor for diesel is 2.63 $kgCO_2$/liter [23].

Solid Waste Indicator

Heating of an alloy to bring it to liquid state for pouring involves material losses. This material loss depends on the furnace design, fuel used, and the method of imparting heat to the metals. Material loss due to oxidation during melting and holding of liquid metal (also known as dross) can be quantified by using the following equation.

$$Solid\ Waste = W_{molten\ metal} \times W_{\%\ of\ meltloss} \quad (6)$$

Melt loss percentage for furnaces is taken from Cast Metal Coalition [24]. For example, induction furnace melt-loss ranges between 0.75 % to 1.25 %.

SUSTAINABILITY INDICATORS FROM SHOP FLOOR

The proposed system utilizes analytics to calculate sustainability indices and is compared using the shop floor data. The following paragraphs explain the procedure adopted for comparing the system with the actual results. This is done by taking data from two die-casting companies situated in Northern India.

Energy use indicator

Actual energy use indicator for die-casting process based on shop floor information is calculated by using the following method.

Electrical Energy Consumed

Electrical energy consumption is computed by using parameters like current, voltage and time from the actual measured data. The following relationship [18] is used to find electrical energy consumption, since the equipment was primarily using three phase power.

$$E = \sqrt{3} \times V \times I \times \cos\varphi \times t \quad (7)$$

These parameters are measured from the display panel of the machines installed in the company where this study was conducted.

Quantity of Fuel Consumed

Quantity of fuel consumed by melting furnaces depends upon efficiency of furnaces, quantity and type of material to be melted and required temperature of the charge. Furnace fuel consumption readings are noted from the fuel meter for each cycle. These sub meters are installed on each furnace in the company.

Air emission indicator

A method to quantify energy-related emissions from the actual measured data is presented in the following paragraphs.

Electric Energy Emissions

Emissions due to electric energy are dependent on the Emission factor, which by itself depends on the region in which the company is located. For Northern Grid of India this factor is 0.84 t of CO_2 per MWh of electricity used [21].

Fossil Fuel Related Emissions

The quantity of fossil fuel consumed is noted from the fuel meters. This quantity of fuel consumption can be converted into carbon emissions by using the mathematical relation, which is given in equation 4.

Solid waste indicator

The quantity of solid waste is measured per shift. This waste is represented in *kg* of total casting material used. The data for actual solid waste is based on the average waste per day in a company.

Table 1 Input parameters of sustainability analyzer

Sub-processes	Inputs parameters
Metal melting	Furnace parameters Mass of charge Melting time for the cycle Furnace efficiency Ambient temperature Final temperature
Metal holding	Furnace parameters Auxiliary equipment used Mass of charge Number of holding furnaces per cell Holding time Furnace efficiency
Die-casting (gravity or pressure die-casting)	Die-casting process Shot weight Cycle time for machine Cell number Die-casting machine in use Number and type of holding furnace in a cell
Miscellaneous activities	Transportation Work cell

SYSTEM FOR SUSTAINABILITY ANALYSIS FOR THE DIE-CASTING

The architecture and working of the proposed computer-aided system *Sustainability Analyzer for Die-casting Process* is discussed in this section.

System architecture

The system comprises three modules namely, *input module*, *processing module*, and *result and report generation module*. The architecture of the proposed system is shown in Figure 3. The *input module* prompts the user to input parameters like mass of charge and pouring temperature, while other relevant data is extracted from the system database in an interactive manner. After required data is input to the system the *processing module* determines the sustainability indicators by using science-based measurement methods. The system uses various databases such as die-casting material properties, process plans, die-casting machine properties, furnace properties, machine and other related sources. These databases are stored as a formatted text file, which can be updated as required. The input provided by the user and the output report in the form of sustainability indicators can be saved. The *results and report generation* module provides results in the form of bar charts in addition to spreadsheets.

Working of the system

The proposed system works as follows. The die-casting process is material specific as the selection of furnaces, die-casting machines and its parameters are governed by the properties of die-casting alloy. As a first step, the user selects the metal. In the second step the system prompts the user to select the alloy for a given product. The third step is to select the primary process, i.e., gravity or pressure die-casting. The fourth step is to select the process plan for the product. The system reads the sub-processes from the database and prompts the user to select one of the sub-processes. After the user selects the sub-process, the system determines the sustainability indices, i.e., energy used, carbon emissions and solid waste.

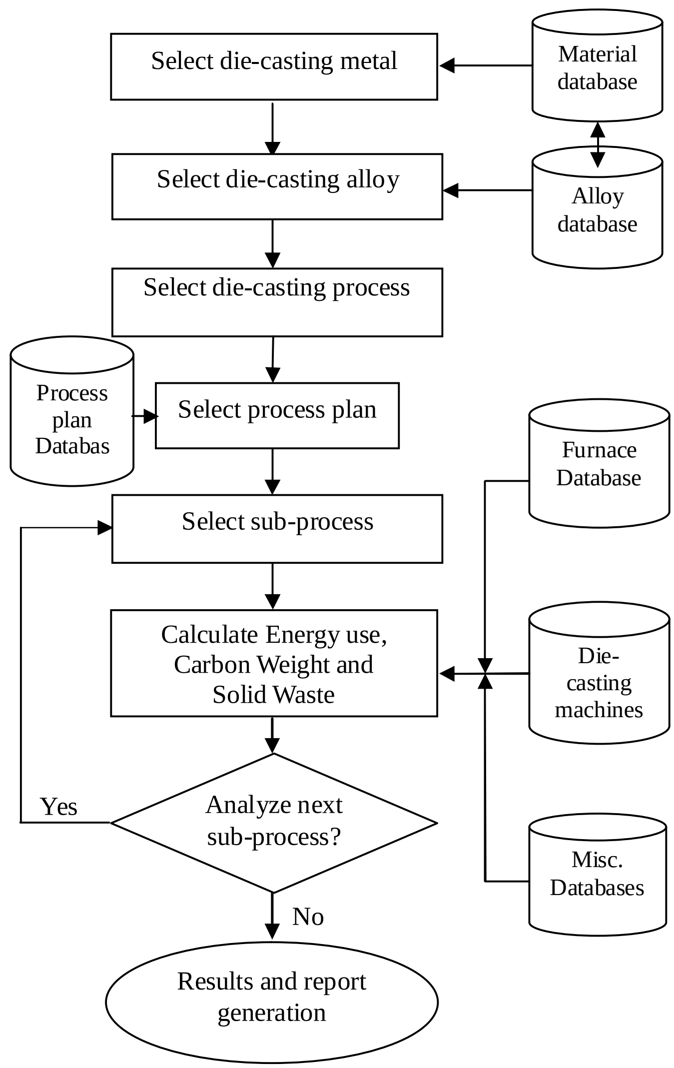

Figure 3 System Architecture of *Sustainability Analyzer for Die-casting Process*

Similarly, depending upon the process plan of a part, different sub-processes are selected by the user and the system calculates sustainability indicators for the process. In the last step results are displayed by the system and these results along with input parameters are saved as a text file. The system input parameters are shown in Table 1. Parameters like mass of charge, melting time per cycle, pouring temperature and ambient temperature are used as input. Total energy consumption, carbon emission and solid waste are used as output parameters. As a feedback to the user, the quantity of fuel is also displayed. A snapshot of the graphic user interface (GUI) of the *Sustainability Analyzer for Die-casting Process* is shown in Figure 4.

Case study 1*: Automotive Piston by Gravity Die-Casting Process*

The first case study is of an automotive piston made using the gravity die-casting process. This case study was conducted at Federal Mogul Goetze, Patiala, India. The component taken in this case study is made up of AC8A alloy of Aluminum and a batch size of 1000 kg is used. During the gravity die-casting process, energy is used for various processes like melting, holding and casting the metal. Besides this, energy is also consumed in lighting, transportation, common facilities and ancillary equipment, which are considered as micro-level activities.

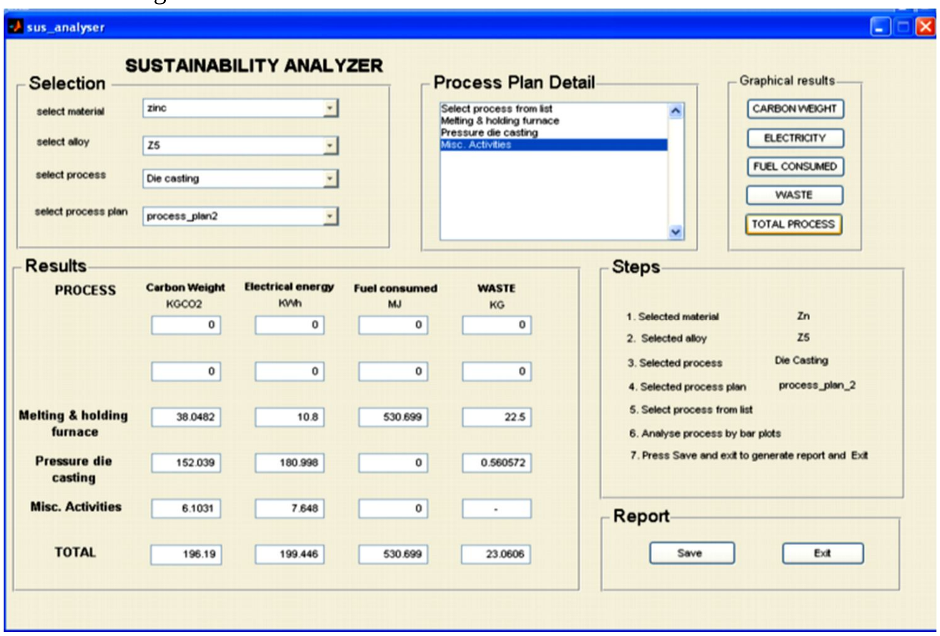

Figure 4 A snapshot of GUI of *Sustainability Analyzer for Die-casting Process*

SYSTEM IMPLEMENTATION AND RESULTS

The computer-aided system for sustainability analysis for the die-casting process was developed on a system with 3.00 GHz processor and 2 GB RAM. A scientific language was used for programming. To demonstrate the utility of the proposed computer-aided system for sustainability analysis for the die-casting process, two case studies are presented in this section. First case study is of an automotive piston made by using the gravity die-casting process. The second case study is a tap knob made by using the pressure die-casting process.

The *Sustainability Analyzer for Die-casting Process* takes the required input information such as mass of charge and pouring temperature from the user. The system processes the input information to determine sustainability indicators. For verification of the proposed system, system results were compared with data obtained from the shop floor. These case studies are presented in the following paragraphs.

Aluminum metal ingots and scrap is the raw material for the gravity die-casting plant. The first step in the die-casting process is preheating the metal. During this step, metal at ambient temperature is heated to 730 °C to 750 °C in a diesel fired tilting reverberatory furnace. The flux is added to the molten metal, which reacts with the impurities to form slag. The slag is then separated from the molten metal to obtain pure metal. Pure molten metal is then transferred from reverberatory furnace to the induction furnace by using an electrical fork lift vehicle.

At the induction furnace site, fresh aluminum alloy is added to the pre-melted charge as per the requirement and temperature of the die-casting alloy is raised. Superheated die-casting alloy is then transferred to the electrical holding furnace, where temperature is further raised by 5 °C. Molten metal is then transferred to the mold in the gravity die-casting machine. After a specific time, molten metal solidifies and the casting is removed from the mold.

Example results obtained from the sustainability analyzer for case study 1 of the gravity die-casting process are shown in Table 2.

Table 2 Results for the gravity die-casting process

Sub-process	Carbon emission (kg of CO_2)	Electrical Energy Consumed (kWh)	Fuel consumed (m^3)	Solid waste (kg)
Pre-melting	247.19	13.30	0.090	44.00
Melting and tapping	2166.80	2605.71	0	10.97
Holding furnace	376.66	448.40	0	6.0
Die-casting machine	109.45	130.294	0	0.62
Micro-level activities	138.30	164.65	0	0
Total	*3038.39*	*3362.35*	*0.090*	*60.97*
Indicator/kg	*3.00*	*3.30*	*9.0E-5*	*0.06*

Table 3 Results for the pressure die-casting process

Sub-process	Carbon emission (kg of CO_2)	Electrical Energy Consumed (kWh)	Fuel consumed (m^3)	Solid waste (kg)
Melting and holding	36.05	10.60	0.531	22.50
Pressure Die-casting	152.04	180.99	0.00	0.56
Micro-level activities	06.10	07.64	0.00	0.00
Total	*194.19*	*199.23*	*0.531*	*23.06*
Indicator/kg	*0.39*	*0.40*	*.0300*	*.046*

Case Study 2: *Tap Knob by Pressure Die-Casting Process*

The second case study is of a tap knob made using the pressure die-casting process. This case study was conducted at HGI Automotives, Faridabad, India. In this case study, zinc scrap and ingots are used as raw material, with a batch size of 800 kg. This raw material is melted from ambient temperature to 440 °C in a gas-fired melting and holding furnace. Molten alloy is then transferred to a pressure die-casting machine, where casting is removed after solidification and the die-cast product is transported to the trimming section. Example results obtained from sustainability analyzer for case study 2 of the pressure die-casting process are shown in Table 3.

Comparison of system results with shop floor data

Results obtained from the proposed system are compared with the measured data from the shop floor and this comparison is shown with the help of Figures 5 and 6 for case study 1 and 2 respectively. Comparison of the results reveals that the carbon weight determined by the system is 4 % (for case study 1) and 5.6 % (for case study 2) higher than the results obtained by using shop floor data. This deviation seems to be due to the reason that we considered rated power of machines while calculating carbon emissions. In actual practice, machines work lower than the rated power. Electrical energy consumption estimated by the system is 6.5 % (for case study 1) and 6.0 % (for case study 2) more than actual shop floor data. Fossil fuel consumption, which was calculated from the actual measured data, is approximately 4 % (for case study 1) and 4.6 % (for case study 2) more than the system-generated results which seems to be due to energy losses. Similarly, solid waste determination reveals an inaccuracy of 6.9 % and 2.5 % respectively. In actual practice, solid waste generation was more as compared to the system results. Solid waste can vary from company to company due to variation in material handling efficiency in addition to furnace operating conditions. We find that system results and actual results differ by a value of 2.5 % to 6.9 %.

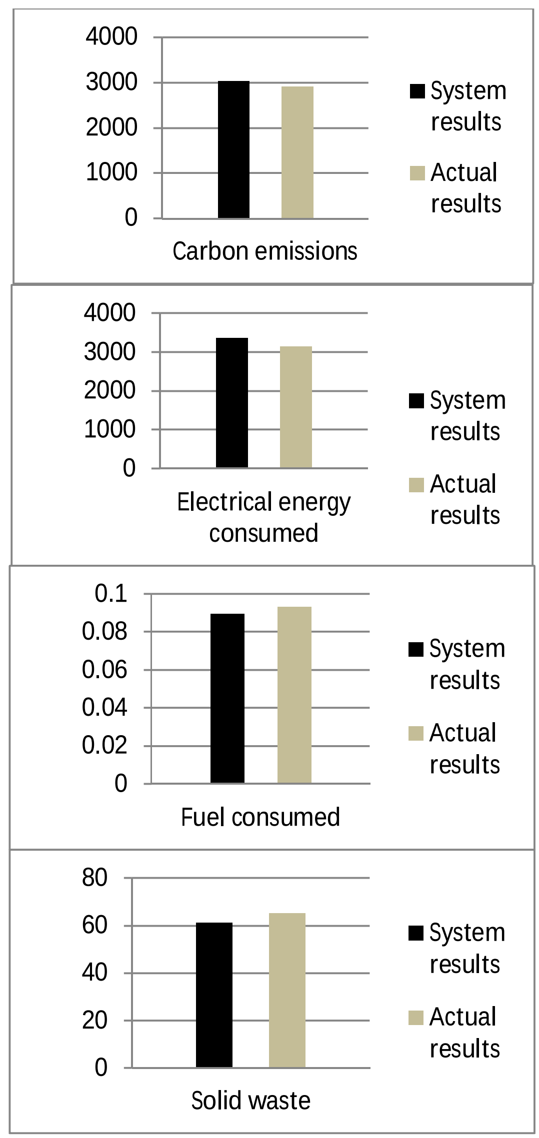

Figure 5 Comparison of system results with the industrial data for case study 1

Comparison of two process plans for manufacturing same part

The developed system was further used to compare the sustainability performance when a part is made by using two different process plans. Here, change in process plans means that different manufacturing resources are used to manufacture the same part. Comparison of process plans from the sustainability point of view is presented in Tables 4 and 5 for gravity die-casting and pressure die-casting respectively. It is observed that two process plans significantly differ on the sustainability performance for manufacturing a part. We found that improvement in sustainability is possible if a better process plan is chosen for manufacturing a part.

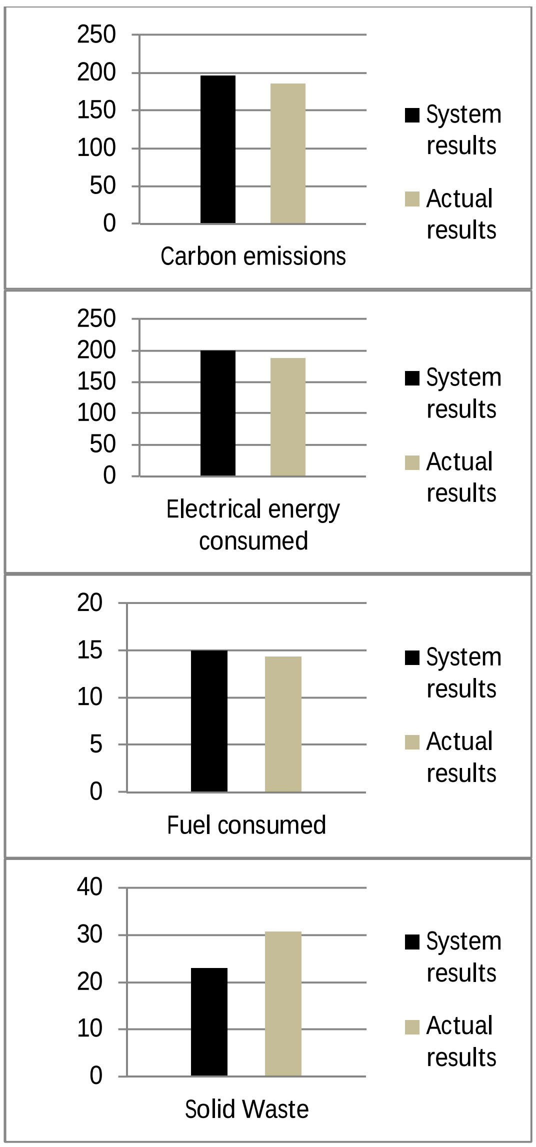

Figure 6 Comparison of system results with industrial data for case study 2

Table 4 Comparison of process plans (Gravity die-casting)

Sub-Process	Equipment used in process plan 1	Equipment used in process plan 2
Pre-melting	Reverberatory diesel fired furnace (SK1) -800 kg	Stack diesel fired furnace (V. AGNI)-1000 kg
Induction melting	Megatherm induction furnace-1000 kg	Piller induction furnace-1000 kg
Molten metal holding	Electrical holding furnace(HF1) 300 kg	Electrical holding furnace(HF2)-500 kg
Die-casting	Gravity die-casting machine 17	Gravity die-casting machine(DCM-9)
Internal Transportation	Electric fork lifter	Electric fork lifter II
Carbon emission *Energy used* *Solid waste*	*3038.39 kgCO_2* *3362.35 kWh* *60.97 kg*	*2907.37 kgCO_2* *3137.35 kWh* *65.84 kg*

Table 5 Comparison of process plans (Pressure die-casting)

Sub-Process	Equipment used in process plan 1	Equipment used in process plan 2
Holding and melting	Thermotech holding and melting furnace	Thermotech holding and melting furnace
Pressure Die-casting	PDCM300	PDCM300
Micro Level Activities	Manual	Manual
Carbon emission *Energy used* *Solid waste*	*196.19 kgCO_2* *199.44 kWh* *23.06 kg*	*219.71 kgCO_2* *229.64 kWh* *23.00 kg*

CONCLUSIONS

A computer-aided system *Sustainability Analyzer for Die-casting Process* was developed and reported. The proposed system is meant for two types of die-casting processes namely, gravity and pressure die-casting. Architecture and working of the proposed system is discussed. Methodology adopted to calculate sustainability based on shop floor information is also presented. Lastly, two case studies are presented to compare system-determined results with those obtained from the shop floor data.

The sustainability analysis of die-casting process is presented using three sustainability indicators, namely air emissions, energy use and solid waste. The system prompts the user to input information or choose process details as per existing set-up through a user friendly GUI. Based on the sustainability analysis we find that process plan and manufacturing resources do affect sustainability assessment for manufacturing. The developed system can be used to assess and compare sustainability for a part made with different process plans.

Presently, *Sustainability Analyzer* can provide results for three indicators only, however in the future it can be extended to include other sustainability indicators. Future work may include extending the proposed system for sustainability assessment of other major manufacturing processes besides including more sustainability indicators.

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DISCLAIMER

Mention of commercial products or services in this paper does not imply approval or endorsement by NIST, nor does it imply that such products or services are necessarily the best available for the purpose.

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