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PERFORMANCE COMPARISON FOR ALUMINIUM, COPPER AND STEEL SHOTS IN WASTE HEAT RECOVERY AND SCRAP PREHEATING FROM SOLIDIFYING MOLTEN METAL

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ABSTRACT

During solidification of molten metal in sand casting, the sensible, latent and superheat are lost to the sand. This research article focuses on waste heat recovery from solidifying molten metal and scrap preheating using the recovered heat. This is done by incorporating an intermediate heat transfer medium such as aluminium, copper and steel shots in green sand mould. These intermediate heat transfer media absorb the heat from the solidifying metal in the mold cavity; the heated shots are separated from the mold and allowed to transfer their heat energy to the metal scrap by conduction, convection and radiation. The experiments prove that 8.4 % of heat recovery is achievable by introducing copper shots with the green sand mold, compared to aluminium shots, which generates 3.7 % and steel shots achieving 3 %. This method has the potential to be instrumental in reducing the enormous amount of energy spent to melt the metal in foundries. The experiments reveal that about 84 kWh of energy can be saved by using copper shots for melting one ton of metal. Cumulative effect of this novel energy conservation method on energy costs and global warming mitigation is found to be very convincing for industrial implementation, particularly for countries such as India.

Keywords: waste heat, energy conservation, scrap preheating, energy saving, eco friendly.

1. INTRODUCTION

Metal casting, being one of the backbone manufacturing industries is an energy intensive manufacturing processes [1]. The Micro, Small and Medium Enterprises (MSME) play a vital role in the Indian economy; there are more than 4500 foundries in India and 80 % of them are small-scale industries. One of the main indicators of resource efficiency of a foundry is energy consumption[2]. Improving output ratio of the molten metal, optimizing moulding parameters, optimizing feeding system, reducing oxidation loss of raw materials, reducing machining allowance, waste heat recovery from flue gases, etc are some of the approaches that can translate into energy conservation [3]. But in metal casting, melting takes maximum energy[4], as indicated in the Figure-1 and hence any attempt to reduce energy consumption in melting will readily translate to substantial overall energy conservation in the casting process. Considering this fact, this paper mainly focuses on exploring a simple, yet novel energy conservation technique in foundries, particularly in the area of melting.

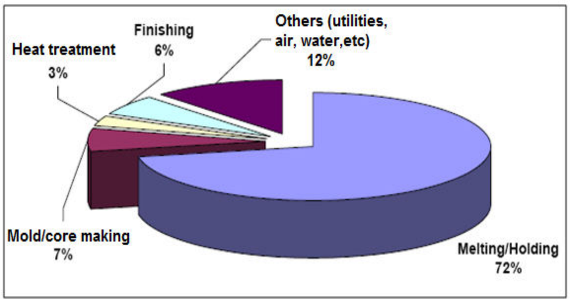

Figure-1. Typical metal casting tacit energy use in different processes

The proposed approach involves waste heat recovery from solidifying molten metal by imparting aluminium, copper and steel shots separately within the sand molds. The heat given out by the molten metal is absorbed by the metal shots and this heat is used to pre heat the scrap material. This pre heating technique can reduce the energy consumption for the melting of the scrap and this result in reduced carbon emission into the atmosphere. The performance of each shot material is analysed to understand its effectiveness for waste heat recovery.

2. LITERATURE REVIEW

Energy conservation in the foundries is usually achieved by recovering the waste heat from flue gas, furnace walls, molten slag and this heat was used for purposes such as steam generation, thermoelectricity, etc. This research work on recovering the waste heat from the solidifying molten metal and employing it for preheating the scrap is relatively new technique. The methodology for preheating the scrap smelting furnace discharge fumes was experimented by Egidio Fedele Dell'Oste [5]. Another technique was developed by Ulrich FH Genge using twin shell electric arc furnace's off gases to preheat the steel scrap[6]. Ghodsipour *et al* conducted experimental and sensitivity analysis of a rotary air pre heater for the flue gas heat recovery [7]. Recent works include an analytical research on Waste Heat Recovery in China's Iron and Steel Industry [8], low-temperature industrial waste-heat recovery in combined heat and power generation systems (WHCHP) and different scenarios were run by computer simulation for WHCHP [9]. A precursor to this work was done to assess the technological viability of the basic concept of waste heat recovery from molten metal by using metal shots and found to be viable [10].

Performance comparison of different heat transfer media was not taken into consideration in the above research work and hence this paper explores that area.

3. METHODOLOGY

The methodology adopted is presented in the Figure-2.

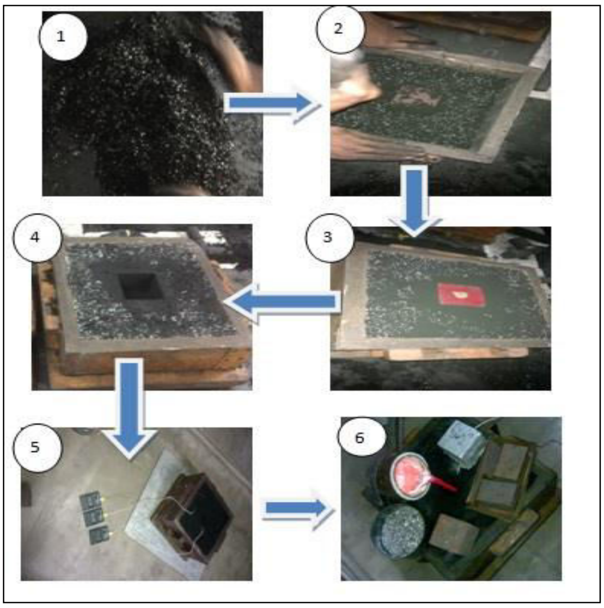

Figure-2. Process flow and experimental setup.

Process flow chart's steps:
1. Preparation of cut-wire shots for mixing with the mold
2. Moulding the drag part with pattern.
3. Completed drag
4. Mold cavity after removing the pattern.
5. Drag and cope assembled with temperature sensors
6. Molten metal pouring

The sand mould is made in such a way that the heat-absorbing materials in the form of cut wire shots are mixed well and are placed closer to the mould cavity so as to absorb maximum amount of heat liberated from molten metal. The experiments were conducted separately by mixing aluminium, copper and steel cut wire shots with the sand mould. Upon pouring the molten metal and during its solidification, the heat gets transferred into the metal shots by conduction and by transferring the energy from the preheated shots into scrap, melting energy can be saved.

4. EXPERIMENTAL SETUP

A wooden cope and drag of dimension 31×31×9 cm was used in the experiment. The pattern used is made of wood with dimensions 7.5×7.3×5 cm. The sand mixed with the shots are placed around the pattern for making the mould. Three K type thermocouples were used to sense the temperature gain of shots. A digital temperature indicator connected with the thermos couple shows the temperature value within the range of -50 °C to 1300 °C. The base metal used for casting was LM25 aluminium. An electric muffle furnace was used for melting the scrap as is the procedure in such contexts [11, 12]. The experimental setup is as shown in the Figure-3.

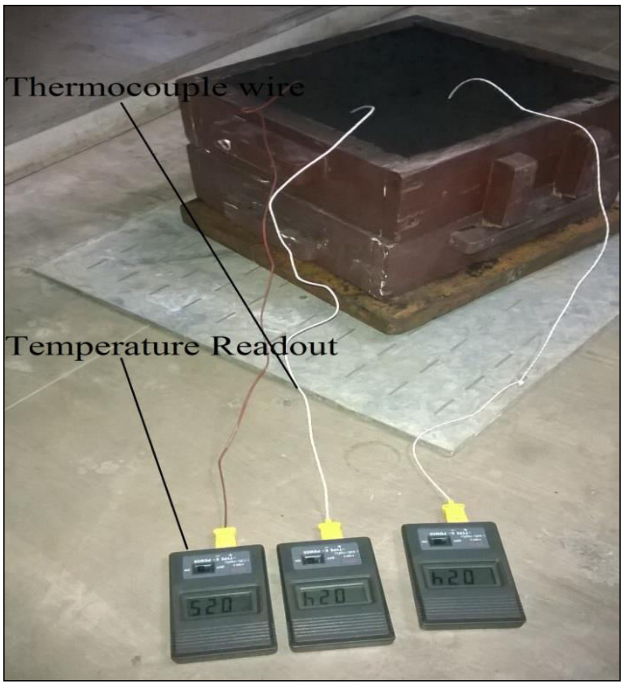

Figure-3. Thermocouple arrangements in the sand mould.

The shots are separated from the sand and scrap preheating, where the scrap at room temperature is mixed with the preheated shots to absorb the heat from the shots.

5. RESULTS AND DISCUSSION

Thermocouple readings in the mold were collected in real time, as soon as the molten metal was poured. The readings indicate the temperate rise in the shots. As soon as the shots reached the peak temperature, they were collected, put into a tray where scrap was kept with thermocouple arrangements. The readings are plotted and discusses as follows.

a. Results of experiment done with aluminium shots

The temperature rise of the aluminium shots are plotted as shown in Figure-4 and it is clear that the maximum temperature that the aluminium shots attained was found to be 118 °C. The thermocouple readings shown during the preheating stage is used for plotting the Temperature vs Time graph as shown in Figure-5. The scrap can take a temperature of 80 °C from the aluminium shots during the preheating stage.

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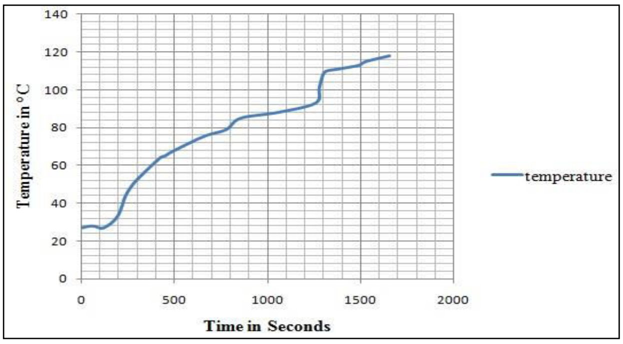

Figure-4. Temperature rise of aluminium shots.

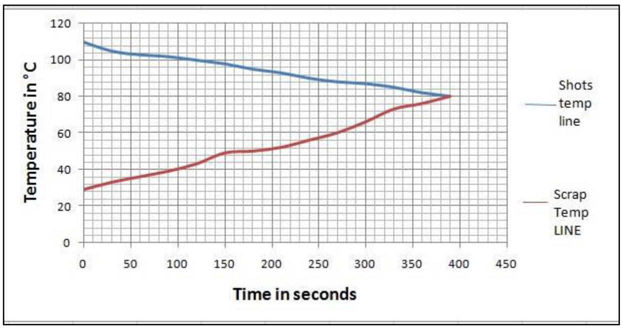

Figure-5. Temperature of scrap and shots.

From the Figures-5 and Figure-6, it is clear that aluminium shots can reach a peak of 118°C and the scrap can take 80°C from the preheated aluminium shots.

b. Results of experiment done with copper shots

By mixing copper shots with the sand mould, temperature gained by the copper gradually increases beyond that of aluminium shots. The temperature rise plots of copper shots are shown in the Figure-6 and it is clear that copper can reach temperature of 200 °C. The preheating readings indicate that the scarp can take 121°C as shown in the Figure-7. The thermal conductivity of copper is higher than that of aluminum and steel, which makes copper to conduct more amount of heat compared to the other two materials.

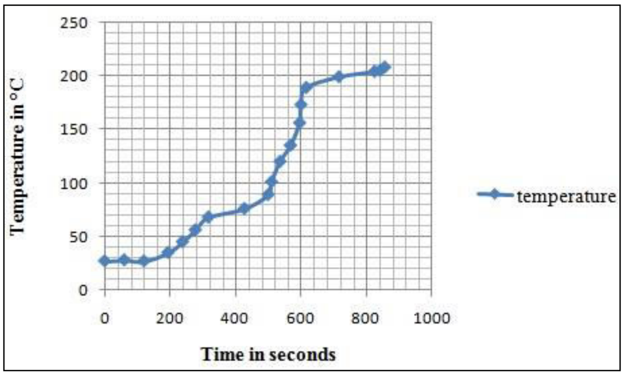

Figure-6. Temperature rise of copper shots.

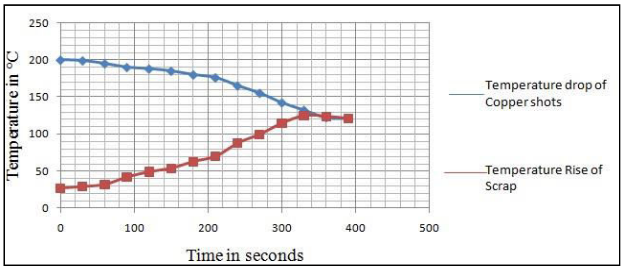

Figure-7. Temperature of scrap and shots.

c. Results of experiment done with steel shots

Steel shots are mixed with the sand mould and the temperature rise graph is plotted as shown in figure 8 and the separated hot steel shots are mixed with the scarp and the temperature rise on the scrap is been plotted as shown in the figure 9. It is studied that steel absorbs less amount of heat compared to other two materials i.e. about 95 °C and scrap absorbs heat of 65 °C from steel during the preheating stage.

Table-1. Maximum temperature obtained by material and scrap.

Shot Material	Maximum Temperature obtained (°C)	Temperature obtained by the scrap during Preheating stage (°C)
Copper	200	121
Aluminium	110	80
Steel	95	63

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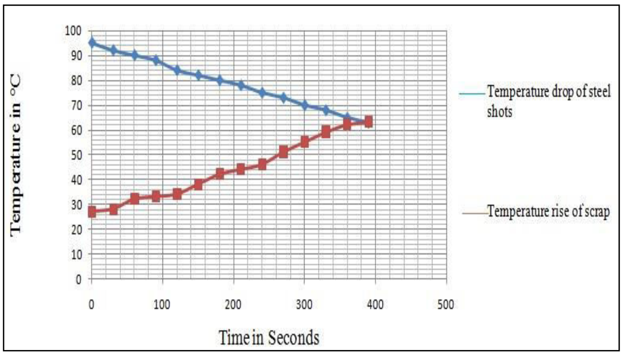

Figure-8. Temperature rise of steel shots.

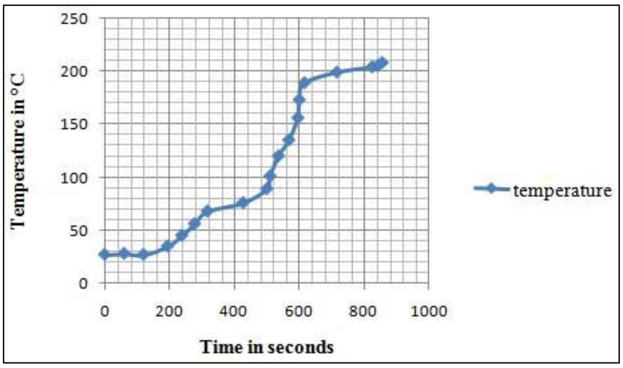

Figure-9. Temperature of scrap and shots.

The obtained peak temperature for the three materials are shown below in the Table-1. It can be seen copper shows higher heat transfer rate compared with aluminium and steel because of higher thermal conductivity.

Energy saving Calculations for Aluminium shots
$E = m \times (c_p(t_m - t)) + m \times (t_m - t) + mc_p(t_p\text{-}t_m)$

m :mass of the casting : 0.92 kg
c_p : Specific heat capacity of aluminum=897 J/kg-K
t_m : Melting temperature of LM25=660 °C
t_p : Pouring temperature of molten metal=750 °C
t:Room temperature=27 °C
E=0.92×(0.897×(660-27))+0.92×(660-27)+0.92×0.897×(750-660))
=1179.00 kJ
Energy recovered=E_r= $mc_p\Delta t$ =0.920.897*(80-27)=43.73 kJ
Percentage of energy Recovered= E_r/E= 3.7%

Energy saving calculations for copper shots
$E = m \times (c_p(t_m - t)) + m \times (t_m - t) + mc_p(t_p\text{-}t_m)$

m: mass of the casting=0.92 kg
c_p: Specific heat capacity of Copper=384 J/kg-K
t_m: Melting temperature of LM25=660 °C
t_p: Pouring temperature of molten metal=750 °C
t: Room temperature=27 °C
E=0.92×(0.384×(660-27))+0.92×(660-27)+0.92×0.384×(750-660))
=837.78 k J
Energy recovered=E_r=mc**Δ**t =0.92×0.897×(121-27)=77.73 kJ
Percentage of energy Recovered= E_r/E= 8.4%

Energy saving Calculations for Steel shots
$E = m \times (c_p(t_m - t)) + m \times (t_m - t) + mc_p(t_p\text{-}t_m)$

m: mass of the casting=0.92 kg
c_p: Specific heat capacity of steel=500J/kg-k
t_m: Melting temperature of LM25=660°C
t_p: Pouring temperature of molten metal=750°C
t: Room temperature=27°C
E=0.92*(.500*(660-27))+0.92*(660-27)+0.92*.500*(750-660)) = 914.9 kJ
Energy recovered=E_r=mc**Δ**t=0.92*0.897*(63-27)= 30.7 kJ
Percentage of energy Recovered= E_r/E= 3

The energy saving calculation indicates that by embedding copper shots with the green sand mould the relatively higher heat (8.4%) can be recovered compared with aluminium and steel shots. Aluminium shots show 3.7 % energy recovery and steel shots shows 3 % energy recovery. The more the conductivity and specific heat values, higher will be the heat absorbed so that the overall heat transfer rate and energy recovery increases so by comparing the conductivity it is clear that copper will have more than aluminium and steel.

6. MICROSTRUCTURE COMPARISON

In order to study whether the properties of the cast product changes by using the shots with the sand mould during casting a micro structure comparison is made for the obtained casted product by embedding the shots and using conventional method (without shots). The obtained microstructure is as shown in the Figures 10 and 11, respectively.

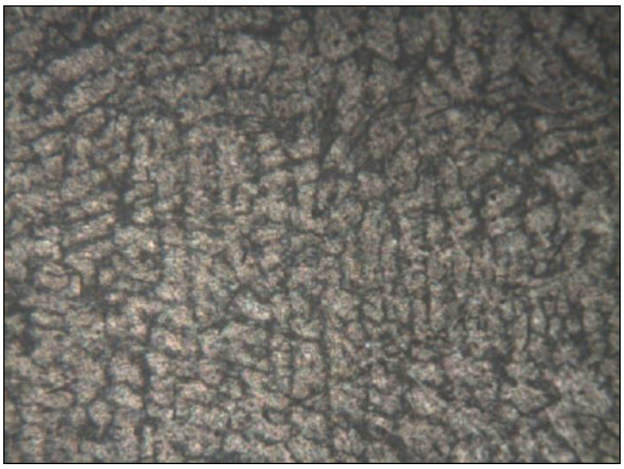

Figure-10. Casting done with shots.

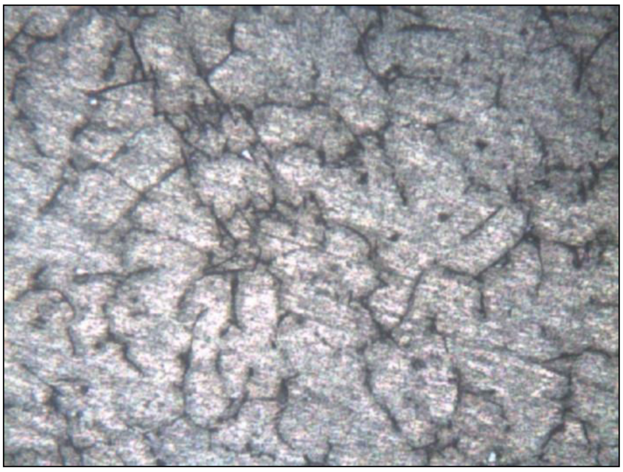

Figure-11. Casting done without shots.

From the above microstructure comparison it is clear that the casting done by embedding the shots in the green sand mould enhances the properties as shown in Figure-12: it's a fine grains structure having a hardness of 84.9 BHN, whereas for normal casting done as shown in Figure-13 has got coarse grain and a hardness value of 76.3 BHN. Since the hardness value lie in the range of 70-100 BHN the properties remains same. The increased hardness is due to the increased cooling rate associated with the embedment of shots [13].

7. ECONOMIC GAIN CALCULATIONS OF THE PROPOSED METHOD

In the present scenario, India produces 11,30000 tons of casting per year [14]. In order to melt one ton of ferrous metal, furnace needs about 650 kWh to 750 kWh [15]. So by using the copper as heat conduction medium, if it is possible to save 8.4 % of the melting energy, it turns out to be 60 kWh. Extending it to the total casting produced, it is possible to save 683 GWh of energy. Applying an average industrial energy cost of Rs. 9 per kWh, this method will save about 380 crores a year, in Indian context. Similar savings can be realized wherever this method is implemented. This shows the strong economical impetus to implement this method.

8. ENVIRONMENTAL BENEFITS OF THE PROPOSED METHOD

Proper implementation of the proposed method has got ecological benefits as much a as it contributes to the economical field. This method helps reducing the emission of CO_2 to the atmosphere, since energy is produced by emissions from fossil fuel sources (particularly in India, where renewable energy's contribution is very less). This method's conservation of 683 GWh of energy will reduce about 352320 tons of CO_2 emitted in to the atmosphere as per the standard ecological foot print calculators [16]. This will save planting about 19873658 trees in order to take in this much amount of CO_2 produced. This method thus plays a vital role in addressing emissions, global warming and climate change.

9. CONCLUSION

This research article compared the performance of three intermediate heat transfer media, in the form of copper, steel and aluminium cut wire shots that are mixed with green sand mold, to extract the waste heat liberated during solidification of molten metal in the mold cavity. The experiments show that by embedding the copper shots, it is possible to preheat the scrap to 121 °C, which is the highest possible. This, when extended to the annual production of castings in India, saves 683 GWh of energy, translating into saving Rs. 380 crores. Corresponding savings in energy-related emissions is found to be 352320 tons of CO_2. Hardness measurements show that the product's mechanical properties are not detrimentally affected by the proposed method. The calculations can also be extended to global energy scenario. In this present context where the conventional energy resources are depleting and energy-related emissions are spelling serious problems such as global warming and climate change, such simple conservation measures as analyzed in this article should be explored more deeply and applied in foundries all over. It should be noted here that the results are from a preliminary investigation only; more detailed experiments are needed to accurately ascertain the energy conservation potential.

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