PRODUCTION OF SPUR GEARS FROM RECYCLED SCRAP FERROUS METALS

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ABSTRACT

Spur gears are important mechanical elements in engineering systems, they are power transmission elements that decide the torque, speed and direction of rotation of all the driven machine elements and the design of such elements is followed by its production (casting and machining). The work presented in this paper was carried out at the Kaduna foundry and machine works, Kaduna in Nigeria and focuses on the utilization of scrap ferrous metal for the production of spur gears. 200 *kg* of scrap ferrous metal was melted in an electric arc furnace using three electrodes each supplying 6,500*A* of electricity with 0.12 *MW* power input. 300 *g* of carbon was added to improve the mechanical properties (tensile strength, hardness and ductility) of the metal that will be subsequently produced. Ten similar molds with circular profile were prepared for each of the following diameters; 130*mm*, 602.74*mm*, 248.19*mm*, 602.74*mm*, 59.09*mm* and 602.74*mm*. Casting was done in a foundry work shop followed by milling process in which the following numbers of spur teeth; 20, 100, 40, 100, 10, 100 were cut on each of the ten similar cast materials. The gears produced can be used for many applications which include production of gear box system, racks and pinions etc.

Key words: Melting, Casting, Machining, Recycling, Scrap metals.

INTRODUCTON

There is a total commitment to reducing the amount of waste sent to landfill each year, the management of municipal solid waste in Nigeria is a major challenge in the big cities like the metropolis of Lagos, Port Harcourt and Abuja. Scrap metals are important components of the municipal solid wastes (MSW) in Nigeria accounting for 18% (Olanrewaju and Ilemobide, 2009), and 10.8% (Ayotamuno and Gobo, 2004) of the MSW generated in the South Western and South Eastern part of the country respectively. Solid wastes are frequently disposed along the streets, gutters, drainage channels, rivers, undeveloped plots of land e.t.c. Poor waste disposal has been linked to blockage of gutters and other drainage channels causing flood and obstruction of traffic flow; poor aesthetics, release of repugnant odour and greenhouse gases; pollution of surface and ground water (Abah and Ohimain, 2010).

Through the activities of scavengers useful materials are often recovered from MSW including metals which are among the most important and most priced materials in MSW, these metals include iron and steel, copper, brass, aluminum (Norgate et al., 2007). Metals play an important part in modern societies and have historically been linked with Industrial development and improved living standards. Society can draw on metal resources from Earth's crust as well as from metal discarded after use in the economy. Inefficient recovery of metals from the economy increases reliance on primary resources and can have impact on nature by increasing the dispersion of metals in the ecosystems. Though the practice of recovering metals for their value dates back to ancient civilizations and today the protection of Earth's resource endowments and ecosystems adds to the incentive for recovering metals after use. Industrial society values metals for their many useful properties. Their strength makes them the preferred material to provide structure, as girders for buildings, rails for trains, chassis for automobiles, and containers for liquids. Metals are also uniquely suited to conduct heat (heat exchangers) and electricity (wires), functions that are indispensable to industrial economies.

According to Legarth (1996), without an intensified focus on recycling, we cannot hope to fulfill even the most modest ambitions for sustainability in the use of metal primary resources in the future. Recycling of scrap metals prevent air, water and soil pollution, saves energy and raw materials, reduce greenhouse gas emissions and also conserve space in landfill sites. Steel is produced from iron ore at high temperature usually in furnace and requiring limestone, coal and power. The process is highly energy intensive. For instance, the production of steel via blast furnace/ blast oxygen furnace (BF/ BOF) has an energy demand of 23 *MJ/kg* and global warming potential of 2.3 $kgCO_2e$ /*kg* (Norgate et al., 2007). Recycling of steel therefore saves energy, material and reduces greenhouse gas emissions. Fenton (2002) reported that recovery of 1 metric tonne of steel from scraps conserves an estimated 1,030 *kg* of iron ore, 580 *kg* of coal and 50 *kg* of limestone. US EPA reported that for every tonne of steel produced from scrap steel saves 111.5 *kg* of iron ore, 625 kg of coal and 53 kg of limestone, using recycled steel saves 75% of energy, 90% raw materials, reduces air pollution by 86%, water use by 40%, water pollution by 76% and mining wastes by 97%.

The objective of this work therefore, is to produce a high quality mechanical element such as spur gear from the recycling process of scrap ferrous metal using an electric arc furnace to achieve the melting process.

METHODOLOGY

Collection of Scrap Metal

The recycling of scrap metals start with the collection of the waste metal. Basically, industries, households and auto-mechanic workshops constantly produce huge amounts of waste consisting of scrap metals that can be recycled. Fig.1 shows the flow chart of scrap metal collection.

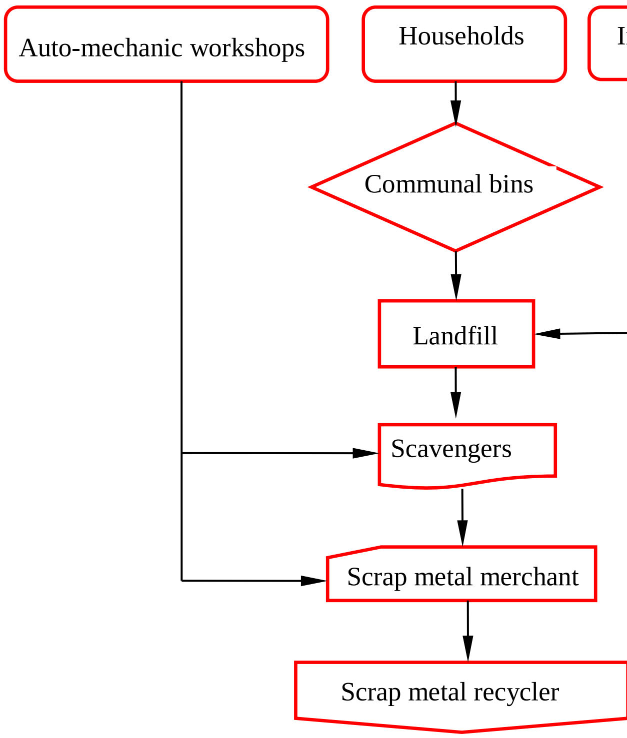


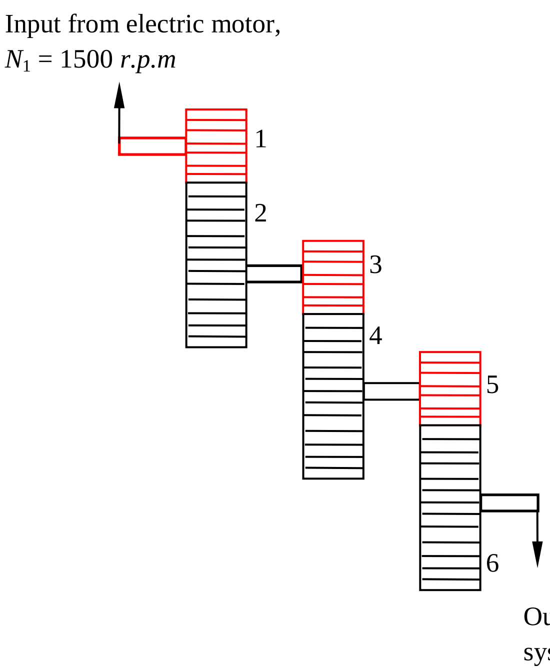
Fig.1: Flow chart of metal collection

Designed Gear Reduction Box for Production

The schematic diagram of the gear box that was designed is shown in fig.2 illustrating the meshing of the gears and the gear train connections. Given that the gear train module is 5.682, then using the formula in eqn.1, the number of teeth and the outside diameter of the gears are calculated and tabulated in table 1

$$M = \frac{OD}{N+2} \quad \ldots\ldots\ldots\ldots \; equ.\ 1$$

M = Module
OD = Outside diameter
N = Number of teeth



The gear ratio, *G.R* is given by the *eqn.1*

$$G.R = \frac{N_1}{N_2} \quad \text{.........eqn. 1}$$

$$= \frac{1{,}500}{12}$$

$$= 125$$

Fig.2 The schematic diagram of the gear reduction box consisting of spur gears and shafts

Table 1: shows the number of gear teeth and outside diameter

Parameter	**First train**		**Second train**		**Third train**	
	Gear 1	Gear 2	Gear 3	Gear 4	Gear 5	Gear6
No of teeth	20	100	40	100	10	100
Outside diameter (mm)	125	579.56	238.64	579.56	56.82	579.56

Preparation of Mold

Ten molds were prepared for each of the diameters (in table 2) in the foundry work shop using wood patterns of the diameter shown in table 2, these diameters were calculated using solidification shrinkage of 4% for the outer diameters of table 1.

Table 2: Amount of shrinkage and diameter of pattern

Component	**Amount of shrinkage (mm)**	**Diameter of pattern (mm)**
Gear 1	5	130
Gear 2	23.18	602.74
Gear 3	9.55	248.19
Gear 4	23.18	602.74
Gear 5	2.27	59.09
Gear 6	23.18	602.74

Fig. 3 shows the molding box and the pattern used to create the impression of the material to be cast while fig.4 shows the schematic diagram of the gating system used for the cavity created by the pattern.

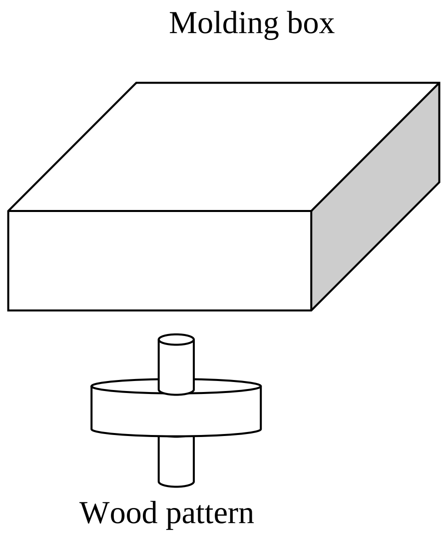


Fig.3: The molding box and the wood pattern

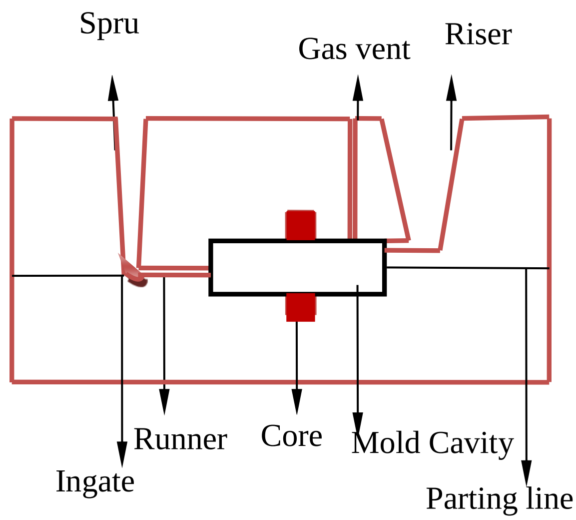


Fig.4: Gating system for casting

Melting of Metal and Casting

The electric arc furnaces (EAFs) are used to produce carbon steels and alloy steels primarily by recycling ferrous scrap. In an EAF scrap and/or manufactured iron units – such as DRI, pig iron, iron carbide – is melted and converted into high quality steel by using high-power electric arcs formed between a cathode and one (for DC) or three (for AC) anodes (Worrell *et al.*, 2010. p. 14). 200 *kg* of scrap ferrous metal was loaded into the electric arc furnace, having three electrodes with power input of 0.12 *MW*. In the process of melting 300 *g* of carbon was added to the molten metal in order to improve its tensile strength and hardness. Alloys and slag forming agents were added in order to remove impurities. The percentage of alloy added is shown in table 3.

Table 3: Weight charts for use in calculation of ferrous heats

Percent of Alloy Additions	**Weight of Element Contributed per 100 Pounds of Charge**						
	FeMn (80%)	**FeSi (50%)**	**FeSi (95%)**	**FeNi (94%)**	**FeCr (70%)**	**FeMo (60%)**	**FeVa (35%)**
0.20	0.160	0.100	0.1900	0.1880	0.1400	0.120	0.0700
.25	.200	.125	.2375	.2350	.1750	.150	.0875
.30	.240	.150	.2850	.2820	.2100	.180	.1050
.35	.280	.175	.3325	.3290	.2450	.210	.1225
.40	.320	.200	.3800	.3760	.2800	.240	.1400
.45	.360	.225	.4275	.4230	.3150	.270	.1575
.50	.400	.250	.4750	.4700	.3500	.300	.1750
.55	.440	.275	.5225	.5170	.3850	.330	.1925
.60	.480	.300	.5700	.5640	.4200	.360	.2100
.65	.520	.325	.6175	.6110	.4550	.390	.2275

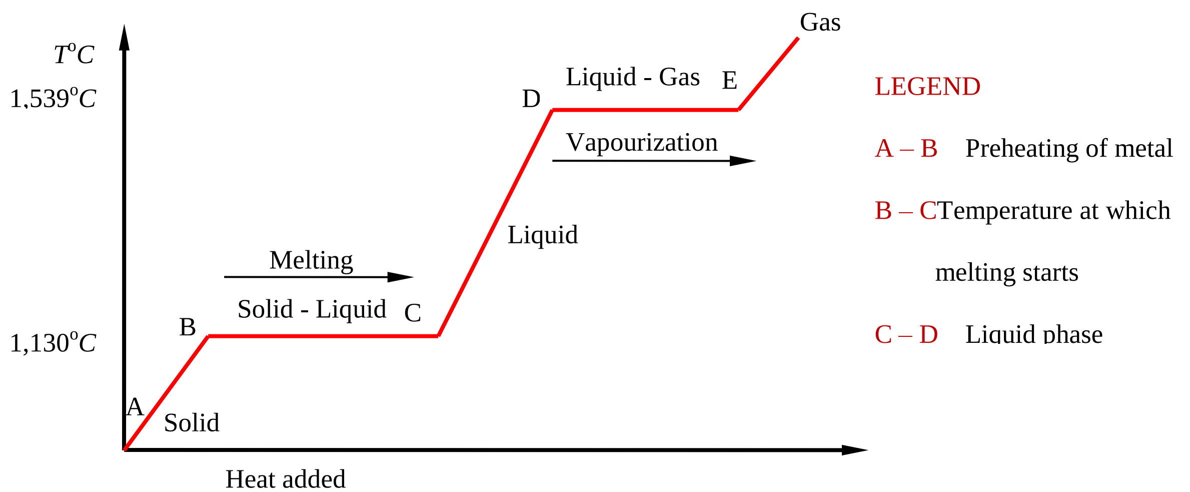
.70	.560	.350	.6650	.6580	.4900	.420	.2450
.75	.600	.375	.7125	.7050	.5250	.450	.2625
.80	.640	.400	.7600	.7520	.5600	.480	.2800
.85	.680	.425	.8075	.7990	.5950	.510	.2975
.90	.720	.450	.8550	.8460	.6300	.540	.3150
.95	.760	.475	.9025	.8930	.6650	.570	.3325
1.00	.800	.500	.9500	.9400	.7000	.600	.3500

The relationship between the melting temperature of the ferrous metals, the amount of heat required and the power input is given in table 4.

Table 4: The relationship between melting temperature and power input

Metal	**Melting temperature °*C***	**Heat input per pound (*BTU*)**	**Input power requirement *Watt* for 300*lb/hr***
Cast iron	1,100 – 1,275	441	77400
Steel	1,425 – 1,539	540	94800
Wrought iron	1,503	617	108600

The heating curve shown in graph 1 depicts the temperature at which the metal is preheated, to the temperature it is melted to the liquid phase.The molten metal produced is tapped with a ladle and poured into the mold cavity under gravity, and allowed to cool to room temperature.



Graph 1: Heating curve of steel

RESULTS AND DISCUSSION

After solidification of the molten metal, it is given heat treatment to improve its mechanical properties accomplished by heating it to a temperature above its upper critical point, holding it at that temperature for a time sufficient to permit certain internal changes to occur, and then cooling to atmospheric temperature under predetermined, controlled conditions. At ordinary temperatures, the carbon in steel exists in the form of particles of iron carbide scattered throughout the iron mixture known as ferrite. The number, size, and distribution of these particles determine the hardness of the steel.The material is turned on the lathe machine to produce smooth surface, this is followed by milling machine operation to cut the number of required teeth on the various materials and finally a slot machine is used to produce the key way for interlocking with a shaft. Fig. 5 shows the flow chart of the entire process of recycling of the scrap metal.

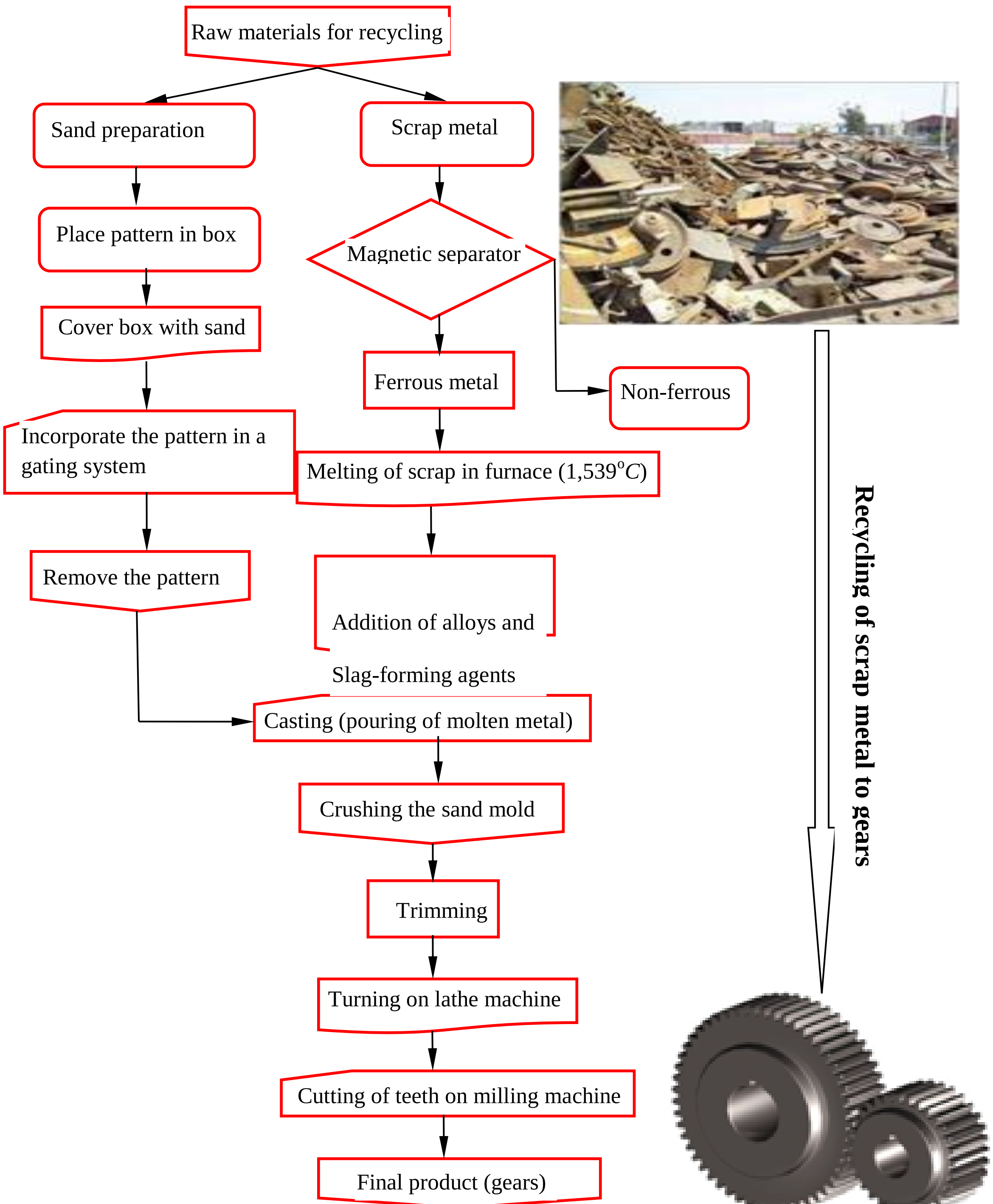


Fig. 5: Flow chart of metal recycling

CONCLUSION

Instead of deploying raw material resources, basic steel elements and valuable alloys can be reused, recycling scrap metals in place of virgin iron ore is beneficial from both economic and environmental point of view and can yield the following benefits: a reduced need in natural resources extraction i.e. by eliminating the costs of implementing the preceding operation's preparation of raw materials (which are seriously depleted by now) and smelting; a broad range of environmental improvements vis-a-viz reduction in air pollution, reduction in water use, reduction in water pollution, reduction in mining wastes and a considerable reduction of fuel consumption needed to acquire raw materials . In general, the capital intensity of using recycled metals is lower than the one from ore.

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