**Abstract**

Metal Chips, especially of ferrous metals, are widely recycled and substitutes metal ores in steel making. The collection, storage and transportation of metal chips is an important aspect in the process of recycling. This project focuses on the compaction and creation of metal chips briquette for ease of storage as well handling and transportation of metal chips as a whole. The project is carried out mainly in two parts. First, the compactor machine is designed keeping the size as compact as possible and ease of availability of materials required to build it. Then the machine is constructed with mild steel sheet metal and other hardened metal objects, later the briquette is studied for its weight, density and compaction ratio required creating it. The briquettes obtained from different compaction methods are compared with the briquette obtained from this machine for its density and compaction ratio analytically. The loss factors are estimated for briquettes in retaining of the lubricants coated on the chips as thin films. These values are compared with analytical estimates in the literature.
1. Introduction

Metal Chips Compactors are widely used machines in recycling plants. Basically, a metal chip compactor machine is one which applies high compressive force on a lump of metal chips which is placed in either an open or a closed die. Because of this mechanical aspect, they are heavy, immobile and they occupy large spaces. They are commonly used in scrap metal yards and industries with high metal swarf, mid-scale machine shops and large scale metal oriented products plants. The objective of the machine is to make the volume of the chips as small as possible in order to have a compact, high density and specific fashion of 3D shape for the purpose of reducing of transportation cost, as well as to gain the more value for chips with same weight. However, these machines are very expensive and are only economical in cases of huge output of chips. The machines used in those industries use the principle of hydraulic power to apply high pressure to achieve better compaction ratio as well as extract cutting fluids coated on the chips. The concept of designing of a size concerned compact and inexpensive machine is an important aspect for induction of chip compactor machines in micro and small scale industries.

The metal chips of various kinds and of different metals possess its own characteristics and require different amount of pressures to compact into briquettes, thus the volume of initial lump of chips for making a specific volume of briquette changes respectively. To way the compaction ratio, it is necessary to know the compression strength and spring effect of the chips, since this allows us to design the machine die cavity from the view point of optimum pressure application for the same force magnitude.

The project is carried out mainly in two parts. First, the compactor machine is designed keeping in the size as compact as possible and ease of availability of materials required to build it. Then the machine is constructed with mild steel sheet metal and other hardened metal objects, later the briquette is studied for its weight, density and compaction ratio required to create it. The results are compared with the available analytical estimates obtained from products of other machines.

The design and the materials required are presented. All conceptual designs presented in this project are drafted using Dassault Systems CATIA.

2. Functional Requirements

i.) The machine should compact to a total ratio of 1:4.
ii.) The machine should produce a total number of 25-30 briquettes per hour
iii.) The total weight of the machine should not be more than 150kg.
iv.) The mounting spring must give a sufficient initial and constant coupling force such that the couple should engage and lift the load without hassle.
v.) The spring must have high repeatability.
vi.) The machine should be completely dismantlable and can be stowed in in small place.

3. Option Studies

- Comparison of optional methods
  The following are the different options available for the selection of compacting methods.

- Metal Scrap Compactor by S.W. Egbert (1908): In this type of machine, it basically uses a complicated linkage mechanism with hydraulic power usage which squeezes the metal in a large bale. The die cavity is set into the ground so as to obtain maximum stability. The machine itself is very large and has to be installed like usual large and heavy machines with heavy foundations. The advantage in this machine is, due to the size of the compactor higher compaction ratio is possible.
Briquetting Machine by R.W. Dinzl (1938): The next versions of briquetting machine came with an advantage of being small and compact when compared to the previous machine. This type of machine used torque to squeeze the metal chips. Torque is applied on heavy screw rod which will turn and reduce the volume inside a die cavity. This mechanism was very capable of producing briquettes of smaller size and denser. The demerit of this machine was its working power required was to be obtained by human effort and proved laborious.

US patent no. US06349638: This machine uses hydraulic power to form briquettes. It has a movable die that provides plural die cavities. In this the hopper is placed directly over the die cavity and hence the ram is in stable condition.

**Selection of alternative**

It was decided to design and develop a metal chips compacting machine incorporating drop hammer mechanism to form briquettes. A drop hammer has the following advantages over other mechanisms:

- The impact load provides more effect on the chips compared to other types of loads.
- Extra absorption of impact energy.
- Good lateral stability.
- The mechanism occupies minimum space in its stowed condition.

### 4. Basic Formulae to Determine the Dimensions of the materials

a) \( PE = mgh \)
   - \( PE \) - Potential energy
   - \( m \) - Mass
   - \( g \) - Acceleration due to gravity
   - \( h \) - Height

b) \( V = \sqrt{2gh} \) [Impact velocity]
   - \( g \) - Acceleration due to gravity
   - \( h \) - Height

c) \( KE = \frac{1}{2} mv^2 \)
   - \( m \) - Mass
   - \( v \) - Velocity

d) \( (16PR)/\pi d^3 \times (1+d/4R) \) [Maximum shear stress in spring]
   - \( P \) - Load
   - \( R \) - Mean radius of the spring
   - \( d \) - Dia of wire

e) Torque \( \tau = \frac{1}{2} \times D \times M \)
   - \( D \) - Dia of pulley
   - \( M \) - Weight of the mass

f) Rate of Discharge from Hopper:
   \[ m = \rho A \sqrt{Bg/(2(1 + m)\tan \theta)} \]
   - \( \theta \) - Semi included angle of the hopper
   - \( M \) - Discharge rate (kg/sec)
   - \( \rho \) - Bulk density (kg/m³)
   - \( g \) - Gravity acceleration (9.807 m/s²)
5. Modeling Of The Metal Chips Compactor

5.1 Die Cavity of the Compactor machine
This concept of design focuses on the weight, simplicity and easy availability of materials. “The compactor machine” term refers to a machine applying compressive force within a boundary, to control the shape given to the briquette. The dimension parameters of the die cavity are presented separately in Figure 3.1.

![Figure 1: The dimension parameters of the briquette](image)

The bottom plate, draw box and the drop hammer together compose the boundary of the cavity.

5.2 Properties of the materials used for machine
The main structure of the machine is made of mild steel sheet IS 432-1 of thickness 3mm. The material properties used in the model are listed in Table 1.

<table>
<thead>
<tr>
<th>Material Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s Modulus (E)</td>
<td>210GPa</td>
</tr>
<tr>
<td>Poisson’s Ratio (N)</td>
<td>0.28</td>
</tr>
<tr>
<td>The Mass Density (P)</td>
<td>7861.093 kg/m³</td>
</tr>
</tbody>
</table>

5.3 Selection of Materials
*Base Plate:* The selection of the metal sheet used for base plate was vital in such a way that the thickness of the sheet is suitable to carry the static load of the other components of the machine without warping but also not exceed the thickness limit which will increase the weight of the machine as a whole. In addition, material should not experience bending until long duration and serve for the life span of the machine. In the process of analysis, special attention should begin to the bending strength of the metal sheet in the best way possible. The aim is to find the most appropriate and efficient thickness for the given mechanical characteristics of the material, therefore 3mm hot rolled mild steel sheet is used.
Body: In this part too, the thickness of the metal sheet is a very important factor. Since the load characters experienced by the body is almost the same as that of the base plate except it is applied longitudinally the material used is hot rolled mild steel sheet of 3mm, same as that of the base plate.

Bottom Plate: The bottom plate is a much thicker piece of metal sheet. This is chosen so, to withstand the recurring impact loads experienced during the working of the machine. Even in this case the thickness is carefully analyzed and used in order to keep the weight low but have the resistance to fatigue. The analysis for the most efficient thickness with a safety factor of 2.5 resulted in 10mm thickness of hot rolled mild steel sheet

Hopper: The hopper is part which feeds the die cavity of the machine with metal chips as and when the slide door of the chips entry is lifted. Since it acts exactly like a container, the loads experienced due to static weight of the metal chips does not severely affect the bounding walls of the hopper. The metal sheet which is used in construction of the base plate and the body is used in making hopper as well.
**Draw Box:** The draw box is a four sided box without a bottom and hence does not experience the effect of recurring impact loads but only the lateral pressure from the compacted briquette. The normal load to the surface of the box walls is high therefore the metal sheet selection with appropriate thickness is important. The box walls are supported with outer walls which are attached to the main body that compliments to the compression strength of the box walls. The metal sheet with 3mm thickness is employed which in turn adds up to 6mm, since the thickness of the outer walls is also 3mm.

**Hammer:** The material chosen for application as a hammer is a 45kg hot rolled piece of billet of dimensions 160mm (width) x 180mm (length) x 260 mm (Height). In addition it is welded with the 8mm metal sheet whose characteristics are similar to that of the bottom plate. The dimensions of this plate is 257mm x 257mm.

**Pulley and Coupling Assembly Mounts:** Here two different gauges of metal tubes are employed, both of rectangular cross section and having cross sectional dimensions of 50mm x 25mm. The heavier gauge tube is used in legs support of the assembly and in the portion of the assembly on which the pulley is mounted. The thickness of this rectangular tube is 1.8mm whereas the thickness of the other gauge is 1mm. The lesser gauge tube is used in the non-load bearing portion of the assembly, on which the motor and the star couples with the shaft are mounted.
Figure 6: Pulley and Coupling Assembly Mount

Machine Mounting Legs: The legs used for the raise and support the whole working portion of the machine is made out of the heavier gauge metal tubes of rectangular cross section, same as in the pulley and couple assembly supporting legs. The legs fixed under the base plate raises the machine to height of 300mm and are 6 in numbers. An extra leg is welded under the bottom plate so as to support and convey the load of the plate to the ground.

Pulley: The focus in selection of the material of the pulley was to reduce weight as maximum as possible but also on the one which can withstand compressive load radially. Therefore the material chosen was Australian Red Maple Wood. Maple wood which is known for its light weight and high strength capability is widely used in construction of make shift buildings and also in constructions of houses in cold countries. The radius of the pulley is 95mm with 40mm thickness. A round shaped 6mm plywood sheet is attached to the pulley on either side so as to prevent the steel rope from slipping sideways.

Shaft: The shaft required here is a 17mm dia. hardened metal rod with 600mm in length. This rod has an intermission at the centre of the couple so as to break the motion between the motor and the pulley while the coupling is disengaged. At both the extreme ends of the shaft metal stoppers are attached to prevent the shaft from having longitudinal relative motion with its mounts.

5.4 Selection of Motor
The motor selected to drive the shaft of pulley and coupling assembly is 12V 5Amp DC motor. It has a torque of 109.6kg-cm at 60 rpm. The DC motor is attached to a gear train which reduces its speed and increase the torque. In addition, the DC gear motor is coupled to two-gear gear train in order to further decrease its speed and increase the torque to 12rpm and 436.2kgcm respectively.

Figure 7: 12v 5Amp DC Gear Motor
5.5 Selection of the couplings: Star Couple

In order to break the rotation movement a coupling was employed between the motor and the pulley. The couple in order to perform the required activity, the couple has to be of a simple design which can be easily engaged and disengaged. Hence for this purpose the coupling faces were required to have contours which grip each other with ease. Since the Star couple has all the required criteria it was selected. A star couple is a solid round shaped piece of cast iron which resembles a crown. The gripping factor comes from the protrusions above the face of the couple that are shaped as molar tooth located on the edge of the face circumferentially. Each of the faces has three such contours. In addition, one of the two parts of the couple is fixed with hard rubber bush for acting as a cushioning agent. This prevents any effects produced during the jerking of the shaft due to load and during engaging/disengaging of the couple, which affects the gears and shaft of the DC gear motor. In the centre of both parts of the couple, a hole is drilled for accommodating the shaft.

![Star Couple](image)

Figure 8: Star Couple

6. Design Of The Metal Chips Compactor

The 3D modeling and assembly design of the entire machine was prepared in Dassault Systems on the basis of collected data from the theoretical calculations & analysis and selected materials. The assemble model is shown in the Fig.9

![Assemble Model](image)

Figure 9: CATIA model of the assembled machine
6.1 Construction of Compactor

Selected metal sheets were marked with shapes and dimensions and were cut. The pieces of sheet cuttings were carefully welded using arc welding. Excessive globs of the welds were grinded in order to achieve smooth finish. First, the body of the machine was constructed and later an entry hole of dimension 200mm x 150mm was cut out. The hole was attached with a sliding door which slides upwards in order to open and shut the entry of the metals. Four pieces of 3mm metal sheet was welded together in order to form the draw box. A handle for pulling out the draw box was attached so that when the briquette is formed it can be easily retrieved by pulling the draw box out of the body. The hopper was later constructed and welded with a heavy gauge metal tube beneath it to support the weight of the chips and the hopper itself. The hopper and the body of the machine was attached together via U-channel and bolts & nuts. Next the legs for the whole assembly were fixed under the base plate at calculated location.

A piece of metal sheet of 10mm thickness which forms as the bottom plate is welded under the base plate at a location which matches exactly with the cross sectional dimensions of the body. Beneath the bottom plate a rectangular metal tube is then welded to support the impact loads of the hammer. Mounts for the active portion of the machine were constructed using a heavy gauge rectangular metal tube. A shaft of 17mm dia. is fixed between the motor and the extreme opposite side. It is mounted on 10mm thick metal plates placed at three locations which is attached with suitable industrial grade ball bearings. A pulley is made out of a light but tough wood with side supports on either side. The circumferential surface of the pulley is covered by a thin metal strip to avoid slipping of the hammer suspension metal rope, which is tack welded.

Small pieces of metal sheet is welded on the surface of the shaft which acts as the gripping agents and slides into the slots made at the centre of the pulley which pushes radially outwards up to 60mm. The couples are fixed between the intermission gap of the shaft. Two mounts, one which is closest to the motor and the middle mount is attached with springs, above and below the ball bearing to achieve constant coupling force between the two portions of the couple. A lever is attached beside the sliding portion of the assembly in order to push it to disengage the couple. Metal rope of 6mm dia. is fixed to the surface of the pulley on one end and the other end is attached with a loop bolt also called I-bolt.

Motor and gear assembly is attached to the sliding portion of the mounting assembly and its shaft is coupled to the main shaft through a two-gear gear train. The I-bolt is fixed to a solid block of metal which forms as a hammer via welded nuts. These nuts are place into the holes drilled on the surface of the hammer. Since the motor works on DC current an AC to DC convertor device called SNPS of 12V 5Amp output, is connected to the motor. The input current is provided by the AC power source.

6.2 Working Mechanism

The basic working principle of the machine is impact load compression. A heavy mass when dropped from a height and is made to plummet on a lump of metal chips, due to high impact load the chips get closer to each other, filling in the gap between them. By repeating this process several times the chips get compacted until they can no more change the shape obtained during the process and hence forming a briquette.

The other mechanisms involved are weight and pulley mechanism and coupling and uncoupling mechanism. The weight and pulley mechanism involves a weight which is suspended via a pulley. The pulley when rotated by the torque applied to its shaft lifts the weigh and when the shaft is extricated the weight falls down due to gravity.
The coupling and coupling mechanism entails a simple apparatus that can hold and release when required and hence breaking the motion and liberating the pulley to drop the weight. The two parts of the couple is attached to the shaft at the intermission. When the couple is engaged, both the shafts rotate at a same speed as one and when disengaged, the part of shaft connected to the pulley is free to rotate independently, but the part that is connected to the motor, continue to turn in the same direction as that of the motor.

![Coupling and Uncoupling of the shaft](image)

**Figure 10: Coupling and Uncoupling of the shaft**

### 6.3 Applications of Metal Chips Compactor
- Salvaging of metals such as: Aluminium, Brass, Bronze, Cast-iron, Copper, Magnesium, Steel, Tire wire, Titanium, Zinc, Most other metals
- Used in: Scrap Yards, Machine Shops, Fabrication plants, Metal parts manufacturing plants and etc.

### 6.4 Advantages of Metal Chips Compactor
- Saves labour time and money
- Increases the value of the scrap metal
- Transportation, handling and storage costs are lowered as a result of the volume reduction
- Cutting Fluids can be reclaimed and re-used
- Improves housekeeping
- Controls leakage
- Alleviate any potential cross contamination with other materials
- Allows you to accurately monitor the amount of scrap being produced
- Increase available floor space by reducing scrap storage area
- Free of coolant, reducing your potential EPA liability

### 7. Results
The Metal Chips Compactor machine makes briquettes out of metal swarfs obtained from the lathe machine that are spiral in structure and has a compression ratio of 4:1 after 10 cycles of hammering. Other type of chips namely the discontinuous and serrated chips takes 12-15 cycles of hammering for compaction. The results are shown below in Table 2.
Table 2: Comparison of properties of the briquette

<table>
<thead>
<tr>
<th>Machine type</th>
<th>Metal Chips Compactor</th>
<th>Hydraulic Briquetter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Briquette dimension (mm)</td>
<td>260 x 260 x 150</td>
<td>120 dia 110 height</td>
</tr>
<tr>
<td>Briquette Volume (cm³)</td>
<td>10140</td>
<td>1244</td>
</tr>
<tr>
<td>Briquette Weight (kg)</td>
<td>10.5 - 11.2</td>
<td>18 - 24</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>1035 - 1104</td>
<td>4300 - 4500</td>
</tr>
<tr>
<td>Compaction Ratio</td>
<td>4:1</td>
<td>12:1 – 18:1</td>
</tr>
<tr>
<td>Lubricant retrieved per ton of metal chips</td>
<td>90 - 150 ml</td>
<td>1100 - 1300 ml</td>
</tr>
<tr>
<td>Throughput (kg/hr)</td>
<td>315 - 400</td>
<td>1500 - 2500</td>
</tr>
</tbody>
</table>

Figure 11: Briquettes from Metal Chips Compactor

Figure 12: Hydraulic Press Briquettes
8. Conclusion

With a conveyor, sorting machine, material level sensor and pneumatic actuated piston disengager, the briquetting press operation can be fully automated. Automating the process gives benefits of reducing the cycle time for producing briquettes. However the cost to produce such automated machines increases and requires skills in programming as well as electronic control systems. It is proved that this machine is capable of handling the amount of metal chips output of micro and small scale industries. The hardness of briquette obtained after destructive testing is up to the level of satisfaction and the current cycle time can briquette an average output of the industry in focus in less than 30 minutes.

References

[14] US patents department