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Reverse Engineering of Reciprocating Saw

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1. Abstract

A reciprocating saw requires many different materials and manufacturing techniques in its design. These materials are selected from a variety of constraints and specific needs depending upon the function of the different parts. In this project, the goal was to disassemble the saw and analyze the different parts, using techniques such as EDS, SEM, and DSC, in order to determine which materials were chosen and why for the design of this saw. Likewise, considerations and ideas for improvements to the saw were taken into account, such as weight, functionality, and price. After some deliberation, it was determined that the materials selected by the company are already representative of low cost and good functionality, but the weight of the tool could be reduced.

2. Introduction

Reciprocating saws (also more colloquially known as a sawzall) are prevalent in DIY home construction users as well as more rugged applications. The tools contain a variety of parts with a variety of compositions which require different methods of characterizing each part as there are quite a few that are integral in the proper function of a sawzall.

2.1 Reciprocating Saw Background

The modern reciprocating saw was introduced in 1951 by Milwaukee under the name Sawzall. It was an electric replacement for the hacksaw. As with a hacksaw, the reciprocating saw cuts materials by forcing a serrated blade back and forth. It is an excellent tool for both construction and demolition because it allows for the quick ability to cut almost any material. However, it also suffers from the fact that it is not very accurate and can easily veer off course of where you are attempting to cut. One of the possible contributors to this is the way that the blade attaches to the saw. Unlike a hacksaw where the blade is attached and supported on both sides, a reciprocating saw only connects the blade at one end. Additionally, the blade needs to be quite thin to be used effectively as a cutting tool. Because of these factors, the blade is not as rigid as a hacksaw blade and thus can sometimes veer off from the course. Additionally, the blade is prone to bending, especially under heavy load because of the heat that is produced.

However, even with these drawbacks, it is an excellent tool to be used for quick cutting necessities which do not require a high level of accuracy. One common application of the reciprocating saw is cutting off portions of an exhaust system of a vehicle when it is being modified. Because of the confined space in which this work must be done, many other cutting tools fall short to the reciprocating saw. Another use is cutting wooden beams in construction as well as in demolition. The reciprocating saw is an extremely versatile piece of equipment. There is a large variety in the price range for these tools, ranging from around $25 to as high as $500. This is because of variations is build quality and materials used, as well as brand named tools versus tools without such high names. The biggest difference in performance in reciprocating saws comes to the amount of vibration that it creates during operation, the ergonomics of use, as well as the longevity of the tool as a whole.

2.2 Characterization Methods

To create a fully-functioning, inexpensive, relatively lightweight sawzall, a variety of materials must be used. In order to determine the composition and processing of these various materials, different characterization methods bust be utilized. Differential scanning calorimetry is characterizes polymers; energy dispersive x-ray spectroscopy, metals; and even qualitative analysis, for others possibly coming from either of the two mentioned classes.

2.2.1 Differential Scanning Calorimetry

One of the most widely used techniques to measure T_g and $T_m$of polymeric materials is differential scanning calorimetry (DSC). This method uses individual heaters to maintain identical temperatures for two small platinum holders – one containing a small (~5mg) polymer sample mechanically sealed in a small aluminum pan the other contains an empty, reference pan. The setup of a DSC can is illustrated in Figure 1.

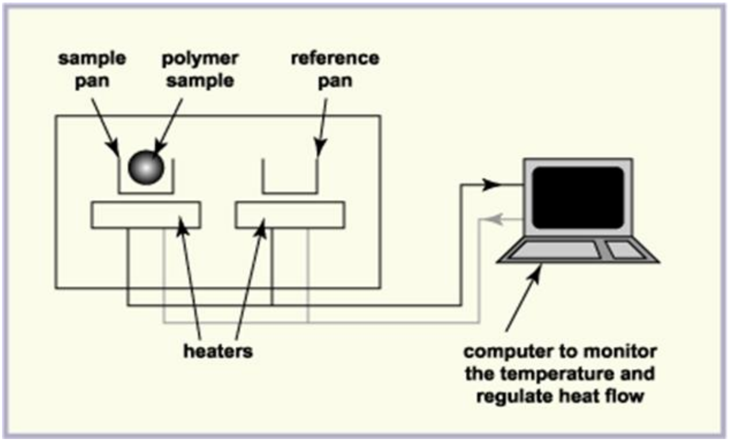

Figure 1 - Schematic of DSC setup

Temperatures are measured by use of identical platinum-resistance thermistors. The differential power needed to maintain both the reference and sample pans at equal temperatures during a programmed heating cycle is then recorded as a function of temperature or time. An example of the resulting curve is shown in Figure 2 in order to demonstrate the key aspects of the curve. The most useful of these facets for this report is the melting temperature. It can be matched with known materials to identify the unknown material being tested. Crystallization temperature can only be obtained in a cooling run which will not be conducted in our experiments. The glass transition can help identify the unknown material in case of several materials being potential candidates based off the melting temperature.

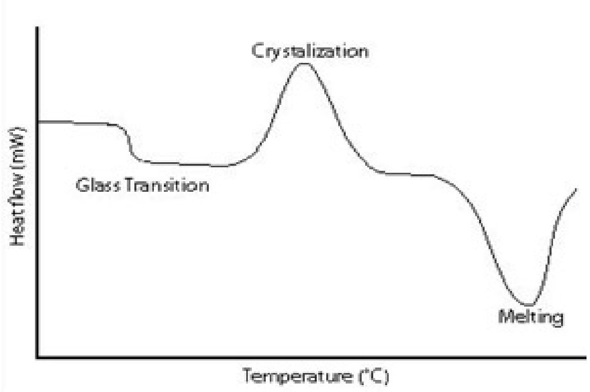

Figure 2 - Rough sketch of a DSC curve to illustrate the key aspects of DSC results

2.2.2 Energy Dispersive X-Ray Spectroscopy

Energy dispersive x-ray spectroscopy (referred to as EDS or EDX) is a simple technique, based on the principle that each element has a unique x-ray emission spectrum, with which the elemental or chemical composition of a sample may be determined. To cause the x-ray emission from the sample, a high-energy beam of electrons is directed at the sample. The high-energy electrons that bombard the sample cause the ground state electrons in the sample to be ejected. This leaves behind an electron hole that an electron from a higher energy state fills, releasing energy in the form of x-rays as it falls to the lower energy shell (as shown in Figure 3).

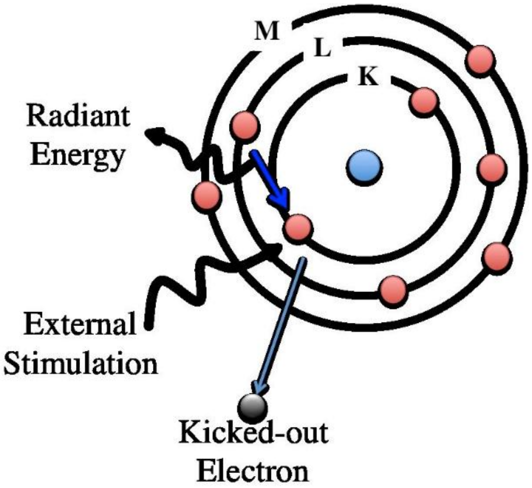

Figure 3 - Principle of Energy Dispersive X-ray Spectroscopy [3]

An energy dispersive spectrometer measures the energy and number of x-rays emitted. The energy of the emitted x-ray is related to the difference in energy between the shells, which is characteristic of each element; therefore, the elemental composition can be determined since each element has a specific energy associated with it.

2.2.3 Qualitative Assessment

While the best ways to obtain precise results are through the previously discussed two methods, amongst others not discussed in this report, qualitative analysis occasionally suffices to make a determination of the material used. For some applications, there are primary materials used with little deviation across all industries that need a material for s given application. Occasions such as this do not require precision in the results, because assuming upon qualitative assessment, it appears to be the commonly used material, then it can be taken as that material. Qualitative assessment includes visual inspection, roughness determination with hands, density determination by holding, ability to be cut with a knife, reaction to proximity of a ferromagnet, amongst other assessment types similar to the ones mentioned. Especially for inexpensive parts, these assessments can yield highly accurate results.

3. Experimental Methods

In order to analyze the parts, it was necessary to entirely disassemble the saw. As expected, the polymer shell was removed to expose the inner parts. Screws were removed in order to reveal the smaller pieces. The larger pieces were cut by using a machine saw in order to make them small enough for the SEM and optical imaging machines. From there, the metal pieces, that were of higher significance to the saw's functionality, were put in epoxy to be mounted and then ground at different levels of grit until the samples were exposed and fully polished for testing. The samples were then taken to the SEM machine to gather data about the different materials' and their elements. The SEM shows graphs exposing the concentrations of these specific materials found in the components, as will be discussed further in Section 4. For the polymers, DSC data was taken to determine the melting point which, in turn, allows identification of the material. Furthermore, some materials, both polymer and metal, were simply identified by qualitative analysis. The use of each piece in the saw, reason for its use, and possible alternatives were identified in order to make improvements to the saw primarily in the area of weight reduction.

4. Results

The methods of disassembling and characterization produced optical images of the deconstructed tool, EDS data, DSC data, and qualitative conclusions. These results will be summarized in upcoming in this report.

4.1 Optical Images

4.1.1 Part #2 - Chuck Ring

The Chuck ring is located at the very end of the assembly of the reciprocating saw and serves as the device into which the saw blade is inserted. It houses a spring which allows it to be twisted to allow a blade to be taken out or put back in, and when released it locks the blade in position.

Figure 4. Chuck ring

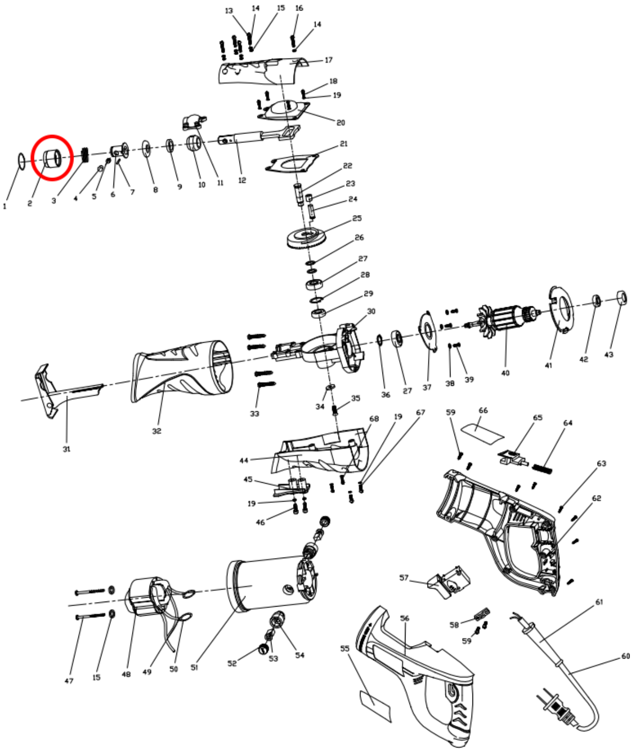

Figure 5. Location of chuck ring

Figure 6. Inner ring

4.1.2 Part #6 - Inner Ring

The Inner ring is the part which the Chuck Ring connects to and rotates around. It serves as a static base for the chuck ring and as an anchoring to the shaft of the tool.

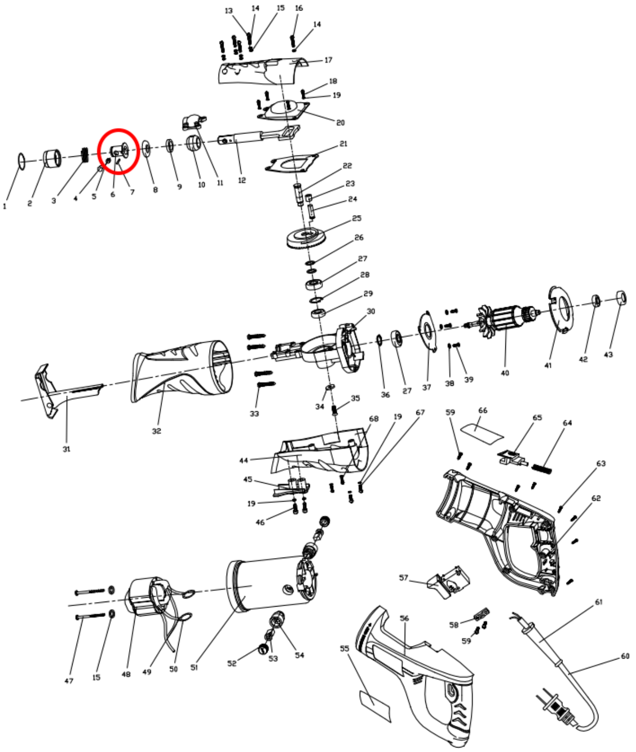

Figure 7. Location of inner ring

4.1.3 Part #10 - Bearing

This bearing acts as a support for the whole reciprocating shaft, reducing the amount of friction produced when the saw is in motion.

Figure 8. Bearing

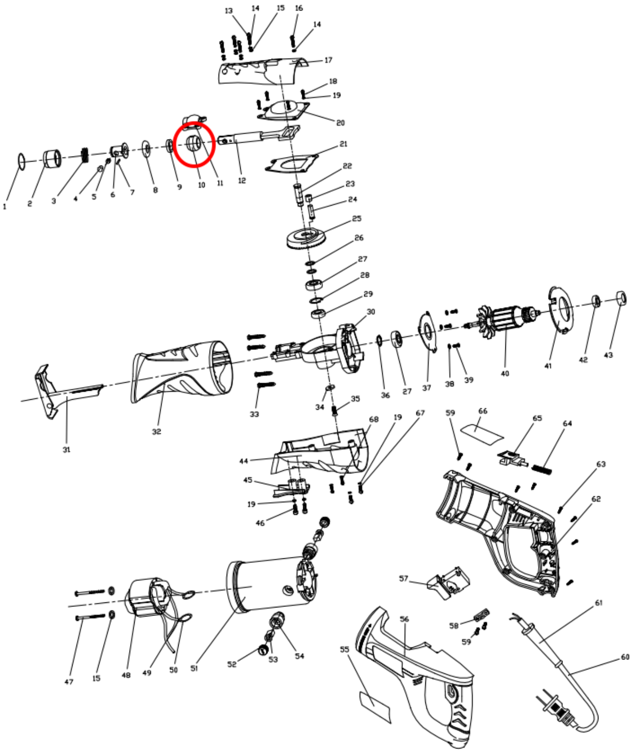

Figure 9. Location of bearing

4.1.4 Part #10 - Ball Cover

The Ball cover acts as a clamp for the main shaft bearing, keeping it in place by being bolted to the main gear housing.

Figure 9. Ball Cover

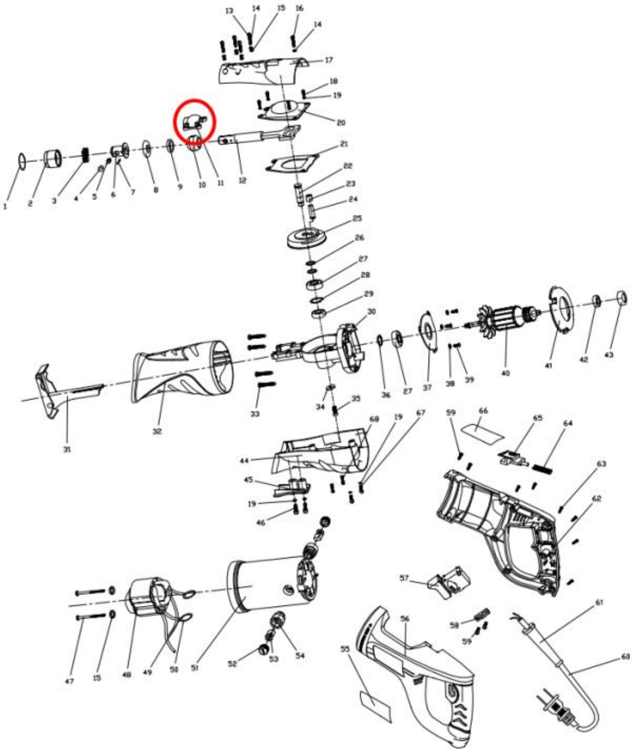

Figure 10. Location of ball cover

4.1.5 Part #12 - Reciprocating Lever

Figure 11. Reciprocating lever

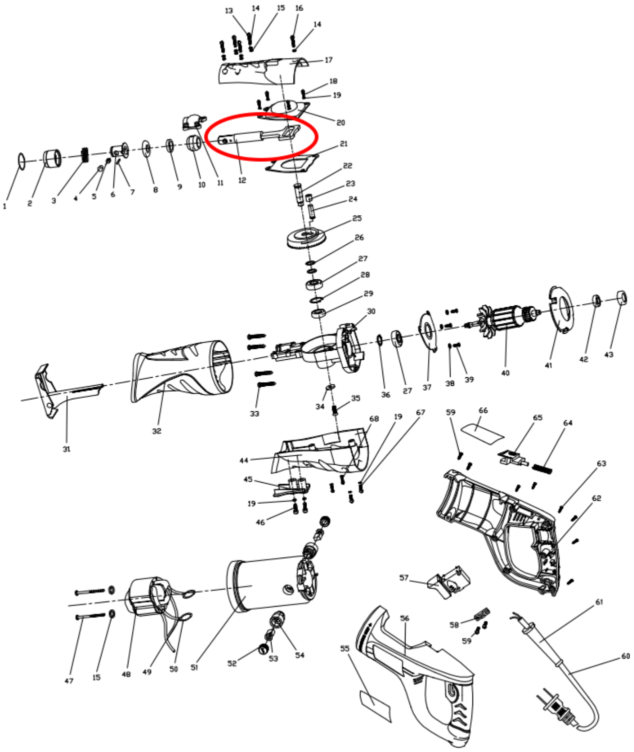

Figure 12. Location of reciprocating lever

4.1.6 Part #32 and #56 - Sleeve and grip

Figure 13. Sleeve

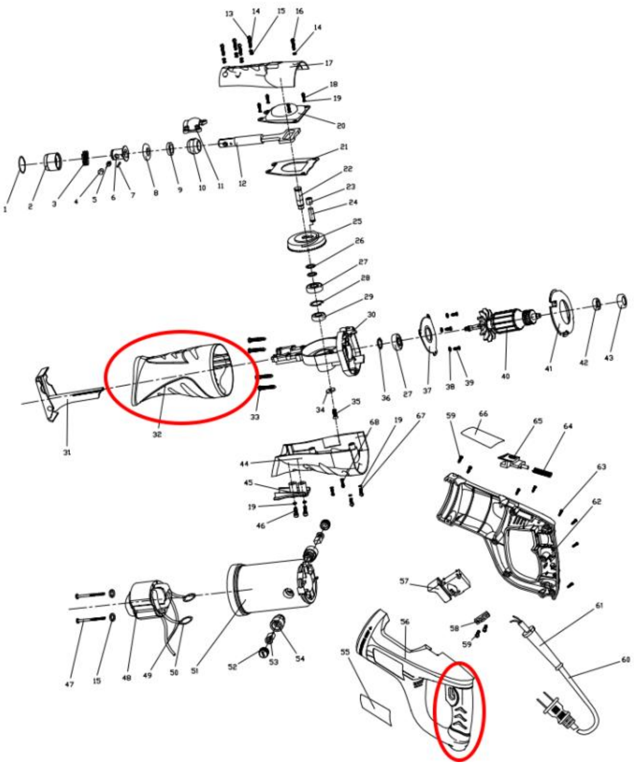

Figure 14. Location of sleeve and grip

4.1.7 Part #60 and #61 - Electrical Outfitting

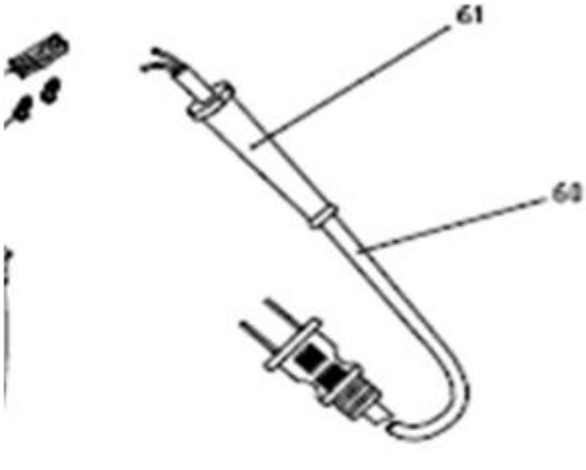

Figure 15. Electrical fitting

4.1.8 Part #20 and #21 - Covering Plate and Gasket

The covering plate and gasket work together to house the area which receives the most heat and abuse. Inside the housing lies the gear which transfers the horizontal rotational motion of the electrical motor to vertical rotational motion. Then, connected to the gear is a pin which is off-center. This then connects to the reciprocating lever to create the axial motion which drives the saw blade. All of this motion can create a lot of friction if it is not properly lubricated, thus the covering plate and gasket contain the lubrication as well as make sure that it does not leak out.

Figure 16. Mounted piece of gasket

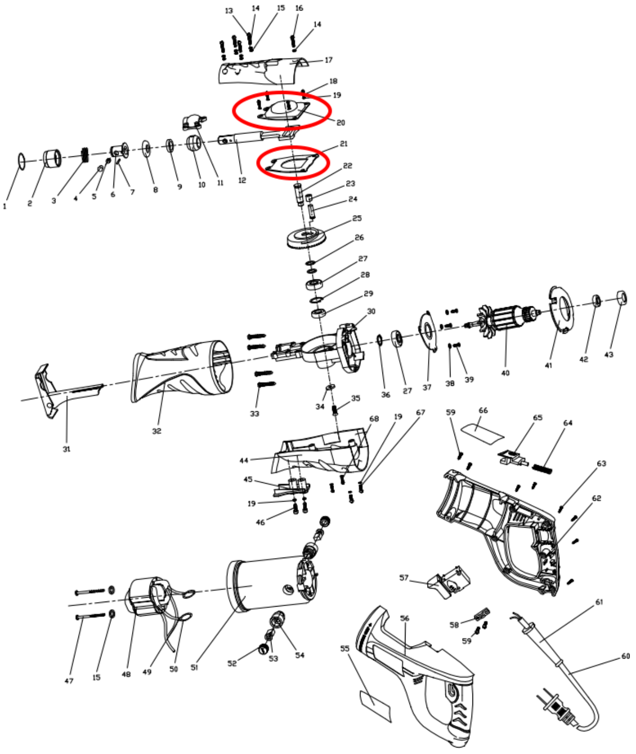

Figure 17. Location of gasket and covering plate

4.1.9 Part #25 – Gear

Figure 18. Top of gear

Figure 19. Bottom of gear

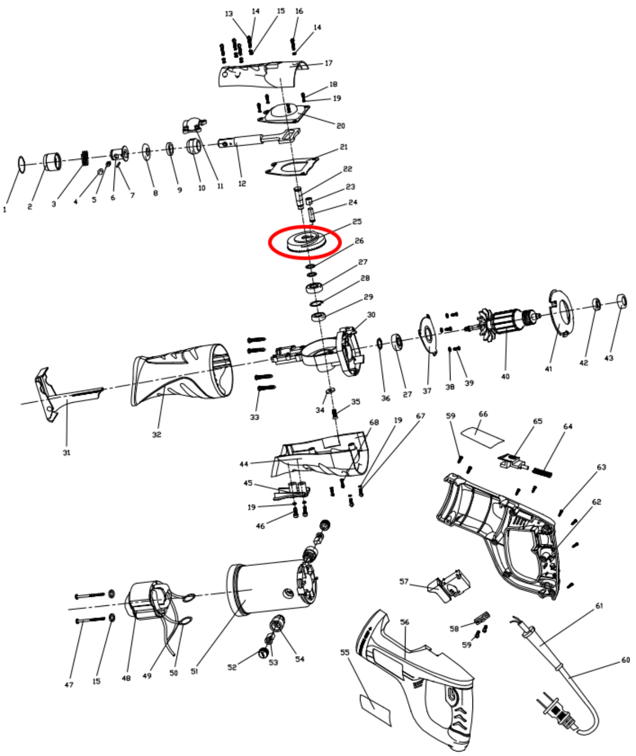

Figure 20. Location of gear

4.1.10 Part #30 - Gear Housing

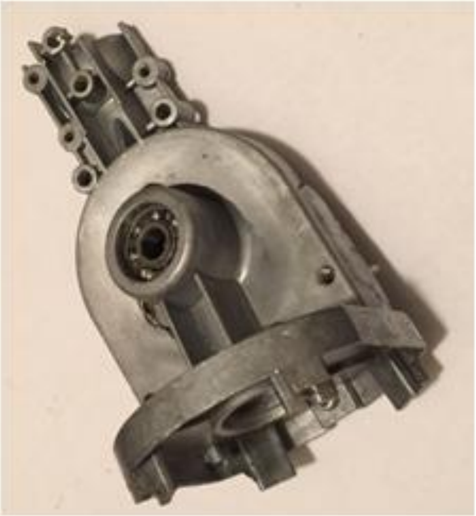

Figure 21. Bottom of gear housing

Figure 22. Top of gear housing

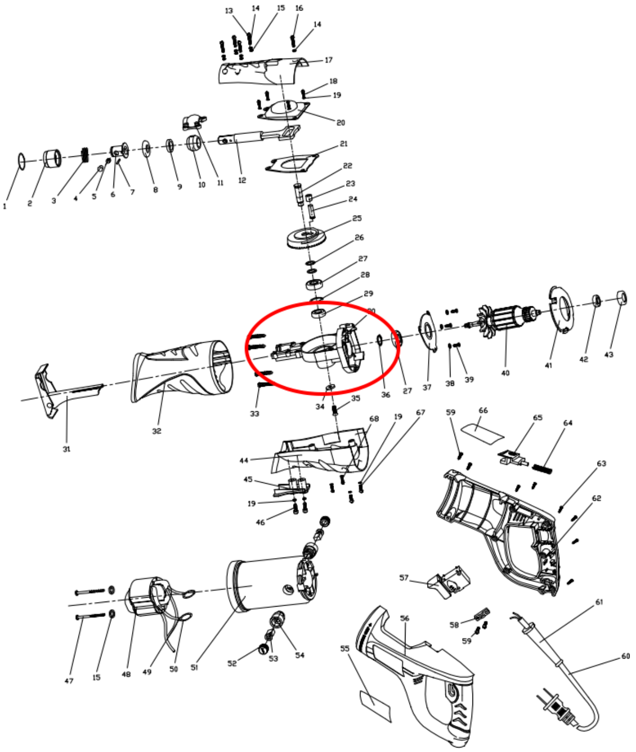

Figure 23. Location of gear housing

4.1.11 Part #37 - Bearing Clamp

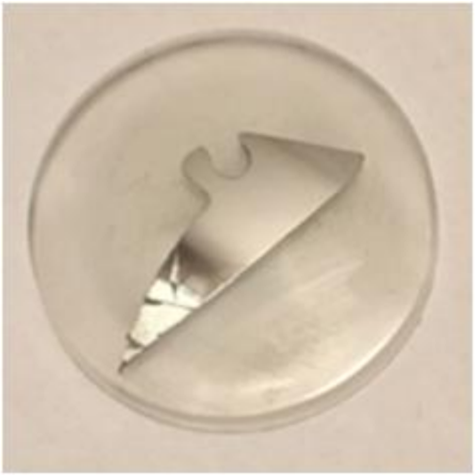

Figure 23. Mounted piece of bearing clamp

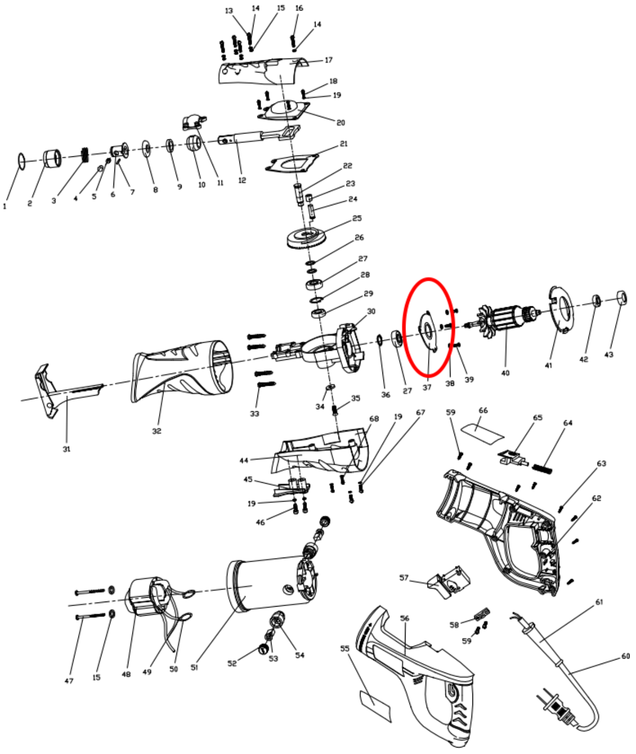

Figure 24. Location of bearing clamp

4.1.12 Part #40 – Rotor

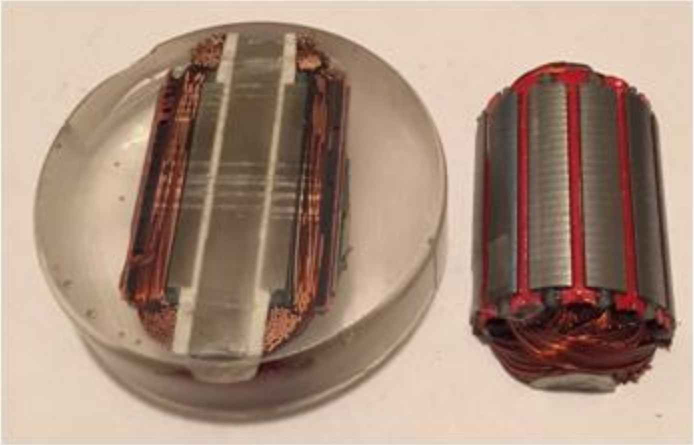

Figure 25. Mounted piece of rotor

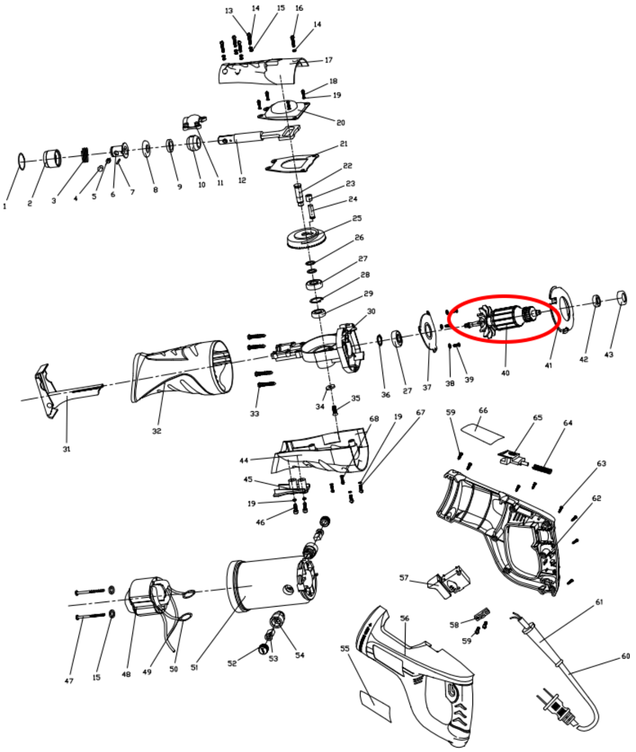

Figure 26. Location of rotor

4.1.13 Part #48 – Stator

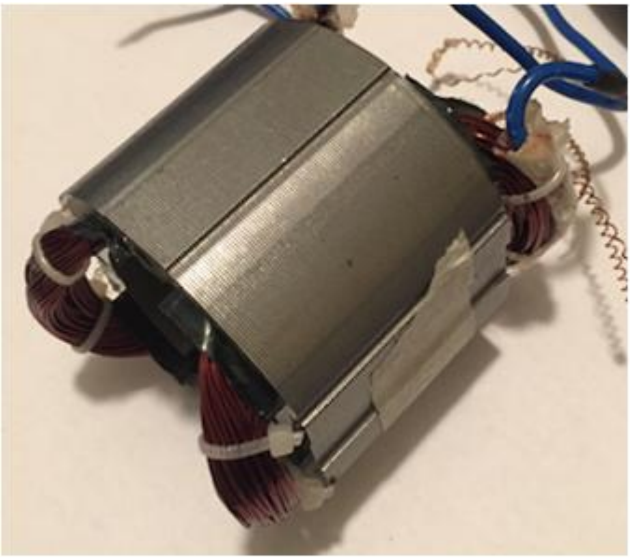

Figure 27. Stator

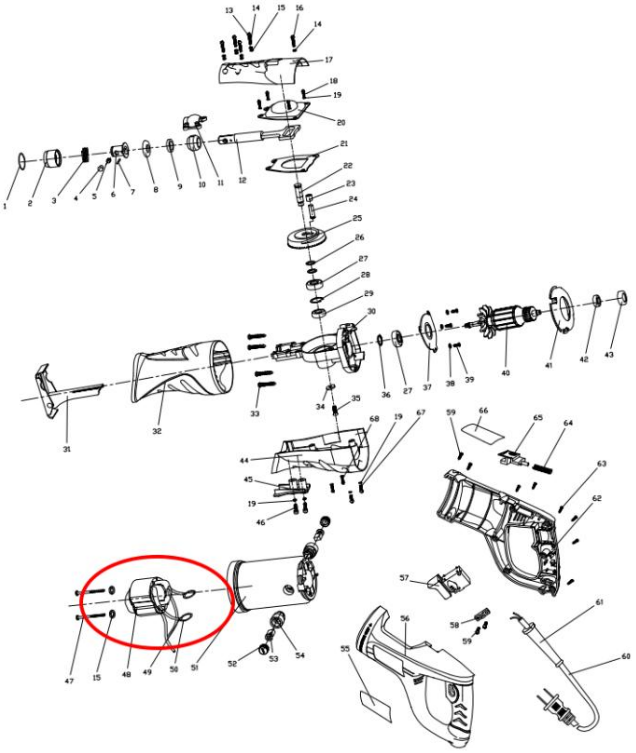

Figure 28. Location of stator

4.2 EDS Data

Table 1 shows the elemental composition of some metallic parts in the saw. The saw contained over sixty parts and most of the parts were the same (i.e. all the screws and bearings); therefore, only one of each different material was tested. However, it must be noted that the compositions presented in the table are not exact due to instrumental errors that cause the concentration of carbon measured to be extremely high. The relative concentrations of each element present, determined by qualitative analysis of the x-ray intensity versus energy graphs (found in Section 8), were used to determine the material of the component.

Table 1. Composition of each unique metallic component as measured by EDS

Content		Carbon	Iron	Manganese	Aluminum	Chromium	Silicon	Oxygen	Copper	Zinc
Part	2	12%	87%	1%						
	6	15%	85%							
	10	18%	82%							
	11	12%	2%		72%		7%	5%	2%	
	20	2%	98%							
	22	8%	91%	1%						
	24	12%	86%			2%				
	25	3%	96%	1%						
	27	10%	88%			2%				
	37	3%	96%	1%						
	48	5%	95%							
	54								62%	38%
	Screw: Base Metal	18%	82%							
	Screw: Coating	17%	74%					9%		

4.3 DSC & Polymer Data

Figure 29 shows the DSC output for part #9, the felt ring with a calculated melting point of ~250°C which indicates that it is polyester which is known to have a similar melting point and by additional qualitative assessment. The felt ring

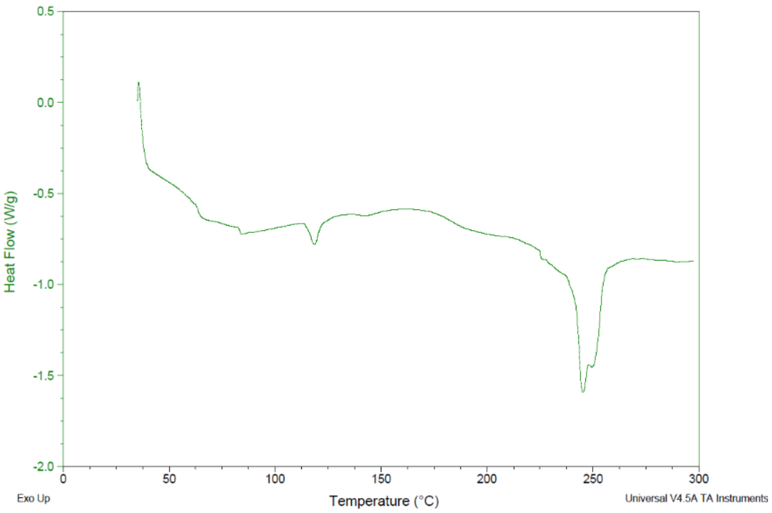

Figure 29. DSC graph of the fabric ring

Figure 30 illustrates a melting temperature of about 215°C indicating the polyamide-6-glassfiller-30 (PA6-GF30 material which has that exact melting temperature in the literature). Many parts of this composition were labeled as such and some were not, but had similar qualitative properties and yielded graphs like the one shown in Figure 30. This material will be discussed in further detail in Section 5.

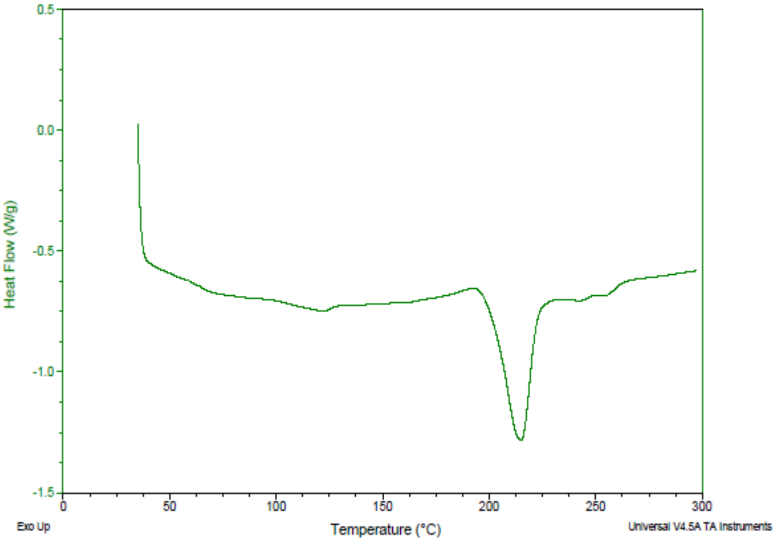

Figure 30. DSC graph of PA6 - GF30

Figure 31 shows a melting point around 120°C for the grip at the rear of the saw indicating it is likely PVC also based on qualitative assessment of rigidity and ability to stretch compared to other PVC in the saw. The melting point of PVC has a large range of melting temperatures based on the degree of crystallinity, but this value lies within the range.

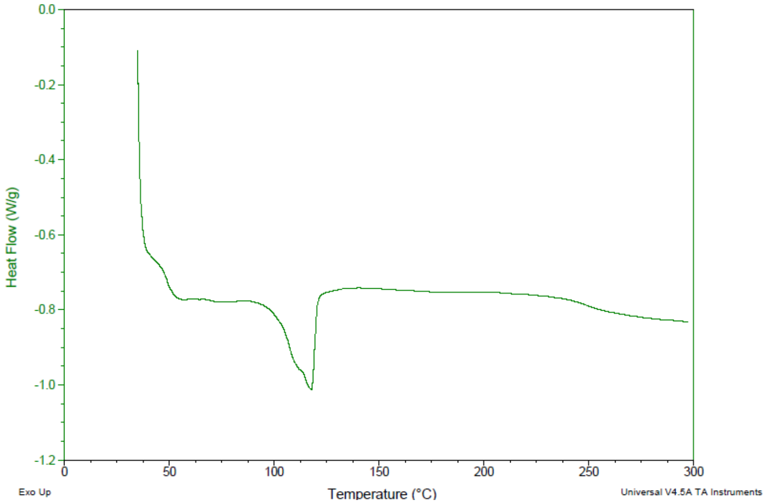

Figure 31. DSC curve of PVC grip on back of saw

Figure 32 shows the DSC data for the wire fixture within that prevents any tension on the wires as they run to the integral electrical components of the saw during plugging, unplugging, or regular movement of the saw. The graph indicates a melting temperature of 220°C which matches that of standard nylon-6. The difference between standard nylon-6 and the PA6-GF30 will be discussed, based on qualitative analysis, in Section 5.

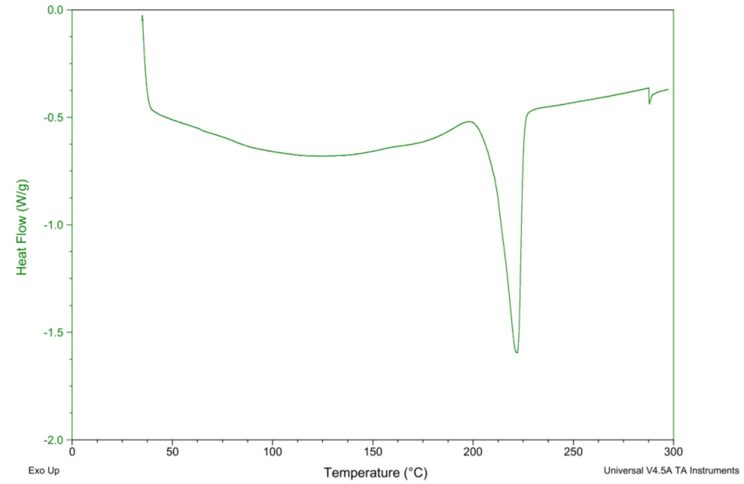

Figure 32. DSC graph of nylon-6 wire fixture

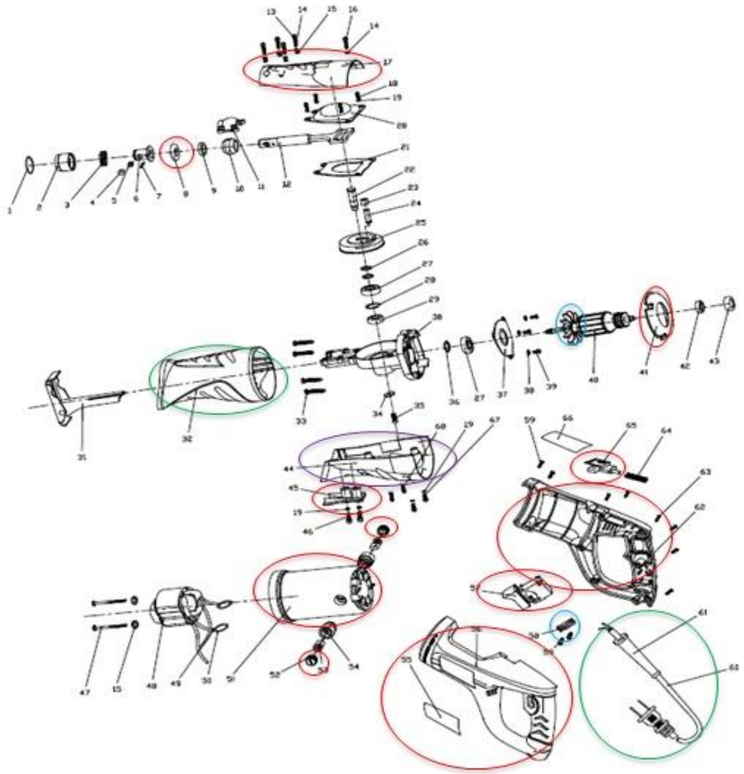

Figure 33. Exploded, color-coded view of the polymeric parts of the saw. Green is PVC; red is PA6-GF30; blue is nylon-6; purple is ABS.

5. Discussion

The most commonly used materials in this product are steel alloys, mostly made of iron with a small concentration of carbon. Steel is used for most of the components because it is strong, tough, easily formed and machined, and extremely cheap. Some of the steel components, those similar to parts 2, 22, 25, and 37, have a small addition of manganese (roughly 1%). This additional alloying element increases the hardenability of the steel; it increases the depth to which the surface of the steel can be hardened after a heat treatment process. Some of the bearings in the product, like parts 24 and 27, are made of stainless steels that contain a small percentage of chromium (about 2%). The addition of Cr to the steel increases its corrosion resistance in most environments and its ductility even to lower temperature.

Aluminum alloys are also used in this product, although less commonly. The aluminum alloys are used specifically for housings because they are significantly more lightweight than steel. For these aluminum alloys, silicon is added to increase the fluidity of the alloy; this allows for easy casting with fine detail and little to no need for finishing. There is also a small addition of copper in the alloys that allow for age-hardening to occur.

One of the components in the saw is made of Naval brass (Cu-40% Zn). This piece is the electrical contact that completes the circuit when the switch is triggered. It is made of brass because it is a good conductor of electricity and it has great formability and machinability with high corrosion resistance.

The screws used to hold the product together are all made of steel, typical for most screws. However, these screws have also been treated to create a black oxide coating. This was accomplished by a chemical reaction occurring on the surface of the steel with the iron to form the compound magnetite (Fe_3O_4). The oxide coating will not affect the material properties of the bulk metal but will provide dimensional stability, anti-galling, improved lubricity, a decorative finish, corrosion protection, and reduced light glare [4]. This surface treatment is the most widely used for all of its advantages because it is one of the cheapest finishing processes.

Polymer processing requires different techniques from that of metal or ceramic materials. A majority of the polymers found in the saw were processed by injection molding. This is distinguishable by the line that separates the part in half where the two mold sections come together as well as the areas that were sanded or cut off from runners. One piece that was not processed in this was the felt ring (part #9, Figure 8). To create the fabric appearance, this polyester was spun and gathered to create the ring-like structure. Injection molding is very efficient and cost effective, explaining the reasoning for the rest of the parts being created through that process.

The most used polymeric material in the saw was the polyamide-6-glassfiller-30. This is 70% polyamide-6, 30% glass filler polymer. The reasoning behind the addition of the glass filler is to lower the viscosity and shear stress of the melt during processing allowing for greater ease in processing. Furthermore, glass filler lowers the cost of the final product while still having many of the same, desirable properties of nylon-6. There were, however, two pieces seen in Figure 12 that were traditional nylon-6 as opposed to the glass-filled variation. The reasoning for this is unknown, but the determination of this was done through quantitative assessment. Comparing the DSC results of Figures 4 & 6, it appears the two materials should be the same, however, after attempting to cut with the PA6-GF30 with a standard pocket knife, it was found to not easily sever but the nylon-6 does, easily. The ease in cutting is a known property of the nylon-6 as it is not as rigid as the PA6-GF30. The PA6-GF30 was used in the tool to provide rigidity and form for the structure of the saw.

PVC was a less used material in the saw, but had two applications. Once in the guiding grip of the saw and in the cord that connects the plug to the wall. The grip was labeled as such and presented a soft surface that allows for ease in holding during use. The wire was assessed via qualitative assessment and comparison with other similar structures. The materials had a similar appearance (rigidity, etc.) to the grip aforementioned in addition to being noted as the primary material for that application. The other grip, on the back of the saw, was determined by Figure 5 as PVC has similar qualitative properties as the other parts known to be PVC.

ABS (acrylonitrile butadiene styrene) had one application in the saw. It is a slightly rigid piece inside the guiding PVC grip at the front of the saw. It was labeled as ABS. The question, though, is what was the need for ABS instead of the commonly used PA6-GF30 for this specific application. The PA6-GF30 has little flexibility which even if inside of a grip would be hard to maintain control of while guiding the blade. ABS is rigid, but also has some flexibility to allow the user to have better grip of the front of the saw and control over the saw blade and its direction.

When it came to possible other materials that could have been used, we turned the material charts in the book. The first on we looked at was the Strength versus Density chart, shown in figure 34. We knew that we wanted as much strength as possible while having a low density to conserve on weight. Aluminum alloys as well as titanium alloys were some possible alternatives, however when we thought about the design specifications of this tool, primarily of it being of the lowest possible cost, we needed to look at another chart. This is where we used the Strength versus Relative Cost chart given in figure 35. This shows us that Carbon steels as well as other steels have some of the best strength for the price. Titanium is much too expensive and Aluminum, while having comparable costs, is outperformed in its strength by most steels.

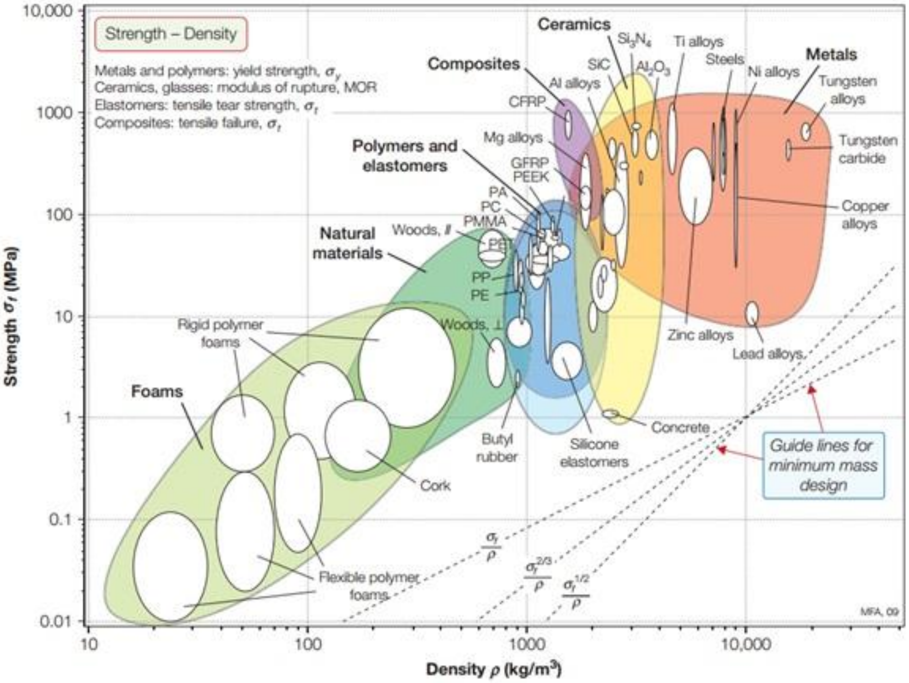

Figure 34 – Strength versus Density chart

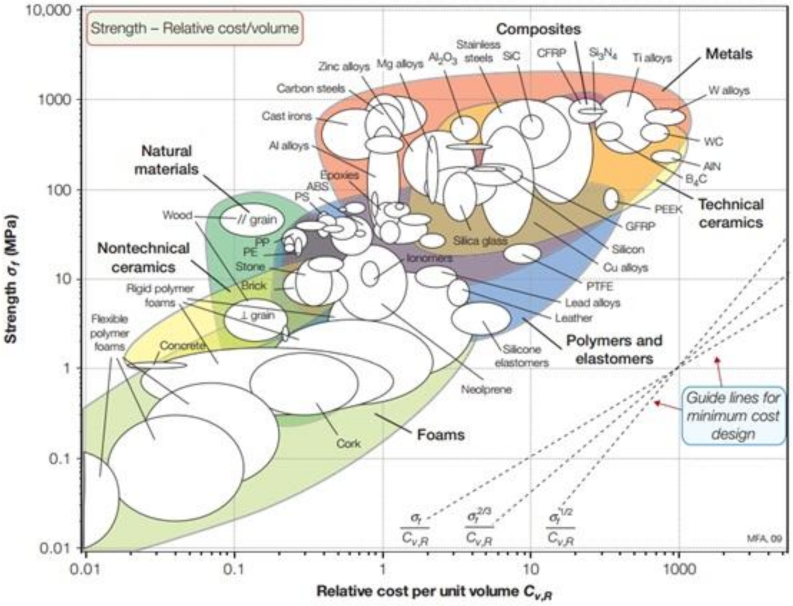

Figure 35 – Strength versus Relative Cost chart

6. Conclusion

As a result of the data analysis from EDS, DSC, and SEM, the majority of the metal pieces proved to be either stainless steel or a variation of carbon steel. These materials also prove to be low cost and adequate for saw functionality; however, other materials such as titanium, nickel, aluminum, and tungsten alloys could be used in place of many of the steel components because they are lighter and have high strength and toughness. However, these materials would increase the cost of production and be more difficult to process. On the other hand, the polymers proved to be PVC, ABS, and nylon variations from analysis. These materials are acceptable for the parts they were used for and improvements seemed unnecessary and less cost efficient. The saw proved to be one manufactured with low cost parts with little regard given to weight or versatility, but only to functionality.

7. References

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[2] Ashby, M. F. *Materials Selection in Mechanical Design*. Oxford: Pergamon, 1992. Print.

[3] "Physical Characterization." The Prashant Kamat Laboratory. University of Notre Dame, n.d. Web.

[4] *What Is Black Oxide?* Walker, MI: Premier Finishing Inc., n.d. PDF.

8. Appendix

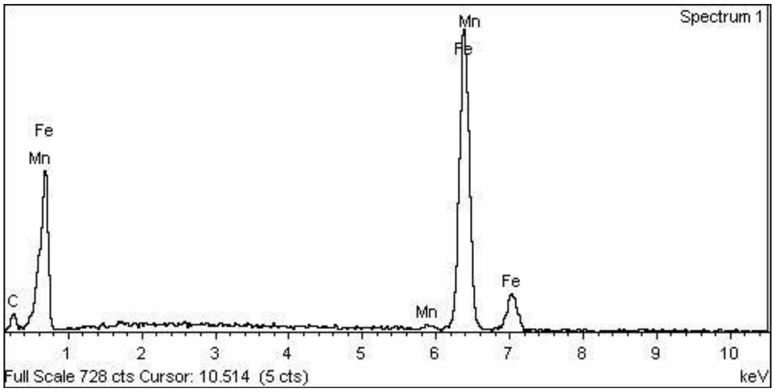

Figure 1A. X-ray emission spectrum for part #2

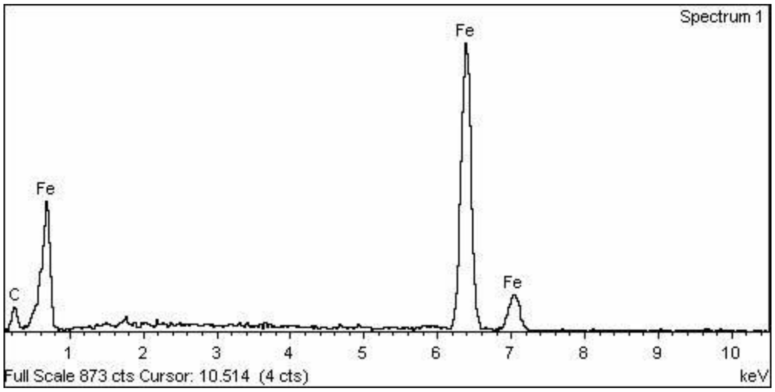

Figure 2A. X-ray emission spectrum for part #6

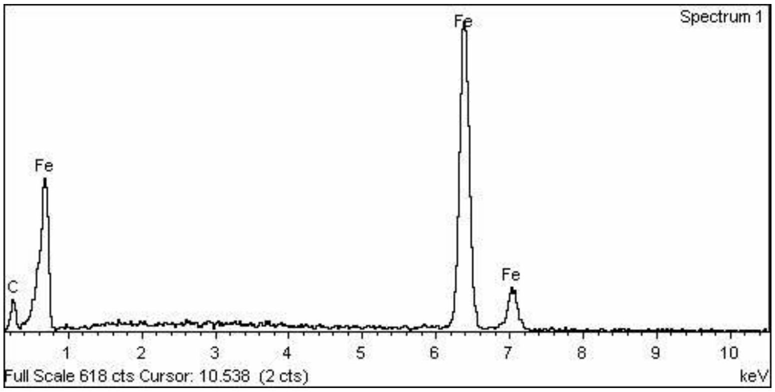

Figure 3A. X-ray emission spectrum for part #10

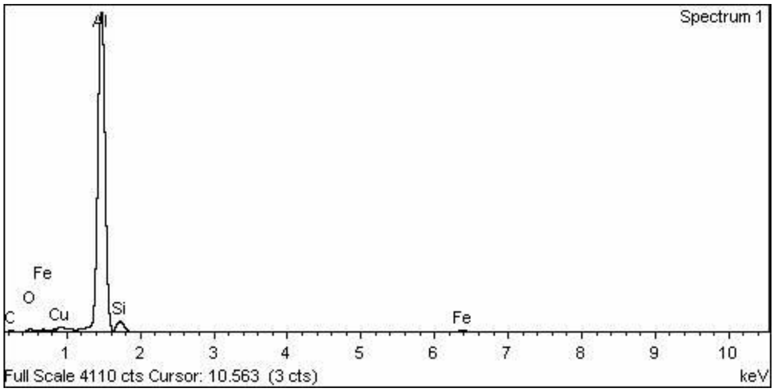

Figure 4A. X-ray emission spectrum for part #11

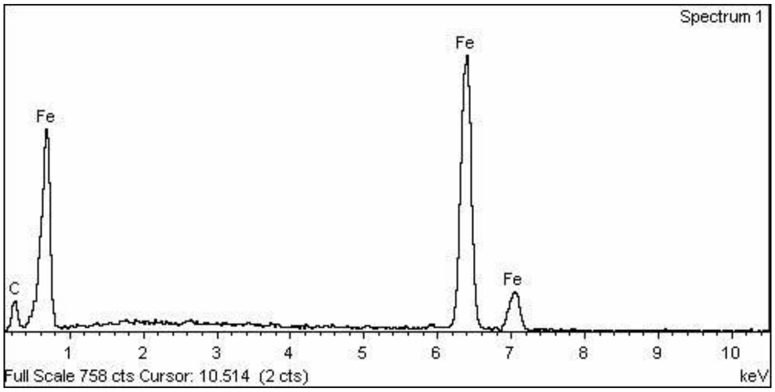

Figure 5A. X-ray emission spectrum for Screws

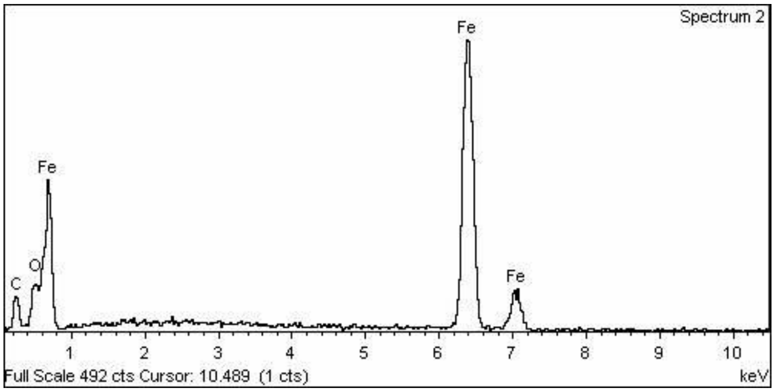

Figure 6A. X-ray emission spectrum for Screws Coating

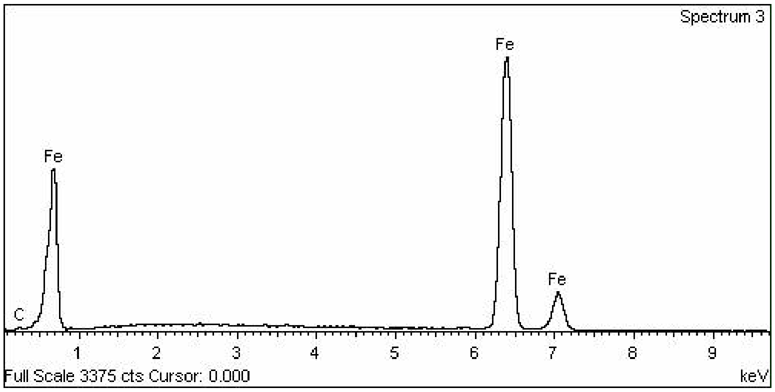

Figure 7A. X-ray emission spectrum for part #20

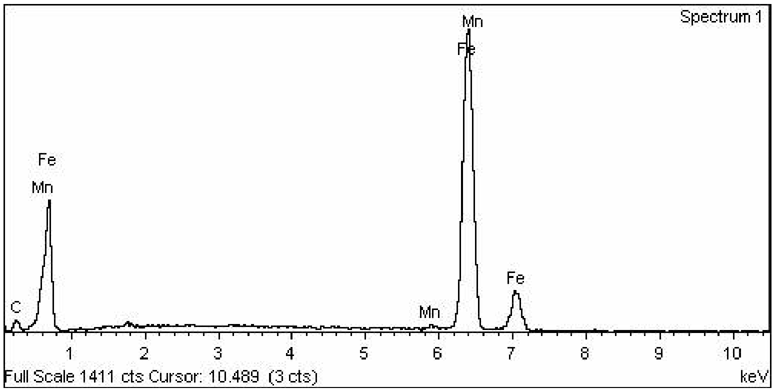

Figure 8A. X-ray emission spectrum for part #22

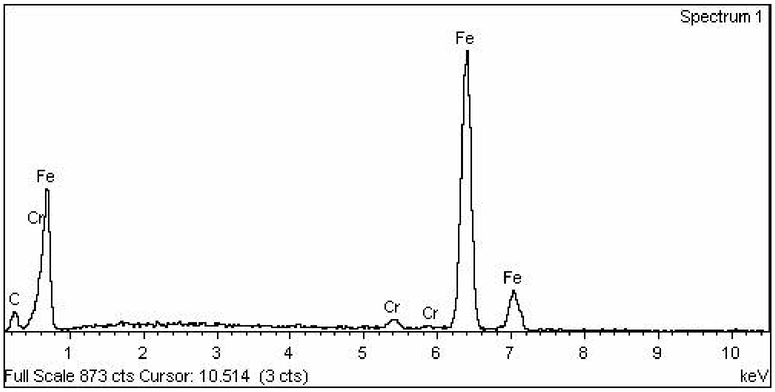

Figure 9A. X-ray emission spectrum for part #24

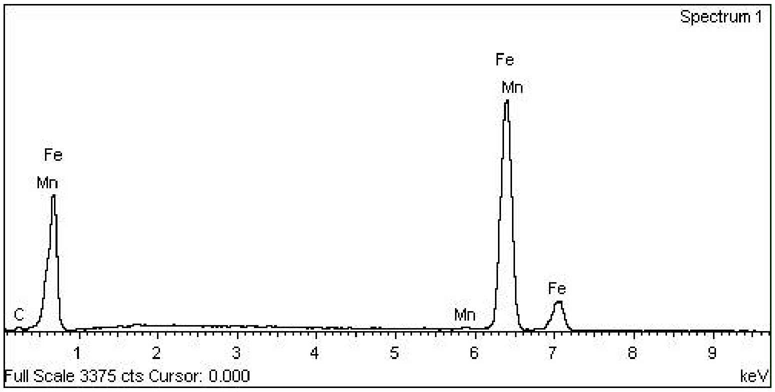

Figure 10A. X-ray emission spectrum for part #25

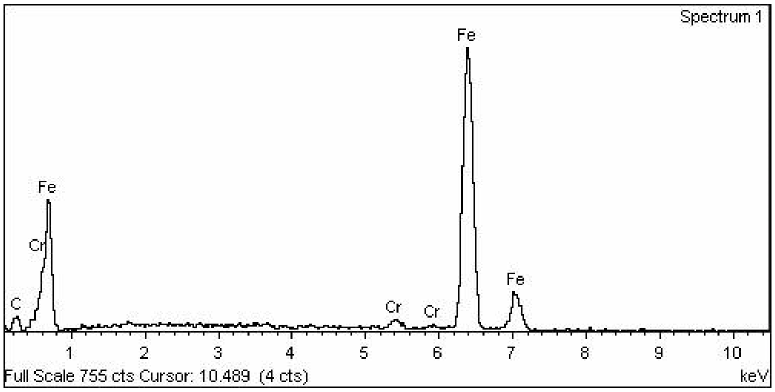

Figure 11A. X-ray emission spectrum for part #27

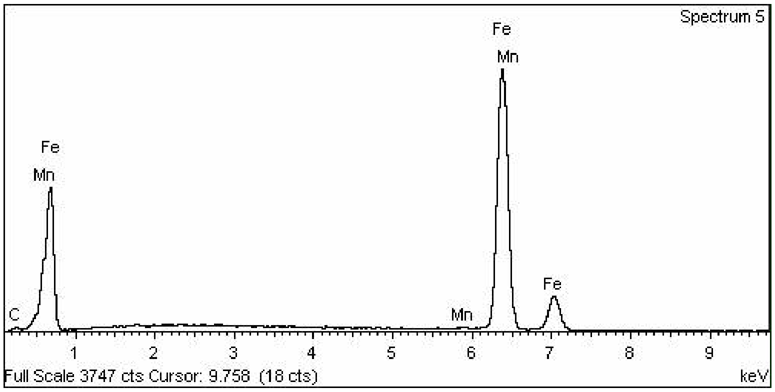

Figure 12A. X-ray emission spectrum for part #37

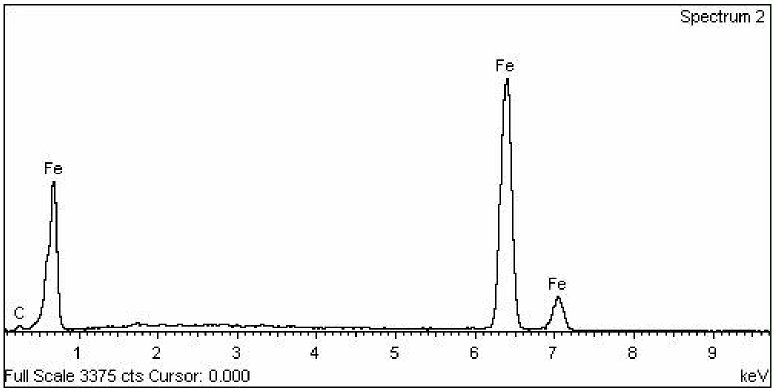

Figure 13A. X-ray emission spectrum for part #48

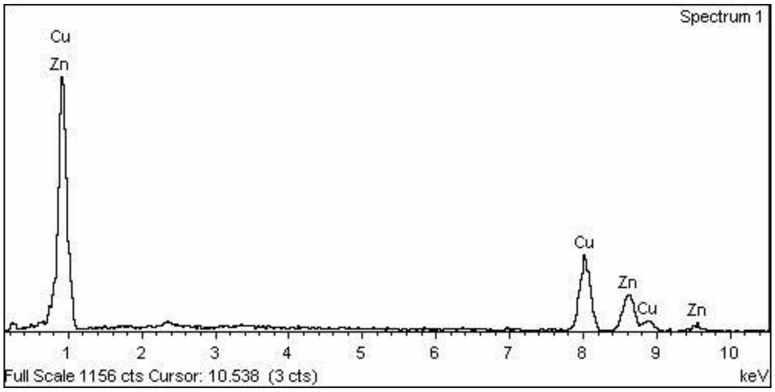

Figure 14A. X-ray emission spectrum for part #54