# Experimental Analysis of Steel Scrap Recycling Property Based on Composition and Mechanical Property Analysis (Case at Akaki Basic Metals Industry -Ethiopia)

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## Abstract:

*Recycling is the method of changing scraps of metals in to useful products following the proper metallurgical requirements and steps. It can be considered as a source of secondary metal Recycling of metals consumes low amount of energy, reduces land fill by waste metal scraps consequently improves pollution problems, uses to produce good quality components ,which in turn is helpful for stainable development of the nation's economy. Recycling of steels is carried out in Ethiopia in different metallurgical industries including Akaki Basic metals Industry. Large amount of wasted steel scraps are accumulated in the compound of the industry. To recycle the steel scrap it was important to analyze the recyclable property of through chemical composition analysis and mechanical property testing methods. Using experimental design methodology recycling of steel scrap of 30kg without analyzing composition was carried out at the Case industry. Melting of steel was carried out using 100kg capacity induction furnace and a 42mm diameter and 500mm length recycled cast steel was produced. A spectroscopic analysis carried out in the particular industry showed that the steel obtained is under the category of carbon steel particularly low carbon steel which the carbon content was 0.21% and tensile strength and hardness test results wear 380Mp and HRC=76 respectively. The result obtained in these three experimental analyses confirmed that the recycled steel has a good recyclable property and the industry can recycle the accumulated steel scraps for pollution protection, economic development of the industry and the country at large.*

**Keywords: Recycle, steel, fracture tensile stress, mechanical property, reduction, de-oxidation**

## 1 Introduction

According to [1] recycling is one of the best risk management tools available, as it allows reducing and even eliminating any risk that may be eventually generated by the disposal of products at their end-of-life .

The recycling of metals can be very efficient with careful selection of the material being recycled [3]. The volume and value of recycled ferrous scrap has led to the development of steel mini-mills which in turn has caused major changes to the steel industry.

Authors [3-4] carried out a research on scrap analysis and indicated in their research that many different types and grades of metals at present fall in the category where recovery is extremely economic with high levels of metals being recovered. Metals can be recycled repeatedly without altering their properties. Steel is the most recycled material on the planet.

Authors [5] explained that the benefits as well as the economics of the scrap metal industry have established a great deal of collaboration between developed and developing countries.

Metals are valuable materials that can be recycled again and again without degrading their properties. Scrap steel has value, which motivates people to collect it for sale to recycling operations. In addition to a financial incentive, there is also an environmental imperative. The recycling of metals enables us to preserve natural resources while requiring less energy to process than the manufacture of new products using virgin raw materials [5]. Recycling emits less carbon dioxide and other harmful gasses. More importantly, it saves money and allows manufacturing businesses to reduce their production cost. Recycling also creates jobs.

Quick Metal Recycling Facts although mentioned that almost every kind of metal can be recycled again and again without degradation of properties, currently, only 30 percent of metal is recycled. Nearly 40 percent of worldwide steel production is made using recycled steel, around 42 percent of crude steel in the United States is made of recycled materials and in the United States alone, around 100 million steel and tin cans are used every day [3-4].Steel and iron are the most recycled materials in the world due in part to the opportunity to recover large structures as well as the ease of reprocessing [4]. The use of magnets in the sorting process enables recyclers to easily separate them from the mixed waste stream. The accumulation of any metal scrap in general and steel in particular results in the land fill, water pollution, air pollutions and the cash tied up, thus it is advisable to recycle the scrap of this metal. Recycling of metals is mostly carried out in metallurgical industries of various categories and levels. Steel scrap is recycled particularly in ferrous metals metallurgical industries.

As of [9] two basic modes of steel making are used worldwide following the procedure as:-the primary and secondary processes. The primary steel manufacturing process comprises iron making in which iron ore is converted into liquid iron (pig iron) followed by steelmaking in which the pig iron is made into steel, casting during which liquid steel is made to solidify into ingots or billets depending on the casting process, billet rolling in which the blocks are reduced to steel bars and product rolling involving the making of finished or near finished shapes.

Authors [8] underlined that the principal raw materials for an integrated mill are iron ore, limestone and coal (or coke), which the materials are charged in batches into a blast furnace where the iron compounds, mainly hematite and magnetite in the ore reduced. The melt in the blast furnace is tapping to molds and forms an ingot that can be further cast or re-smelted to produce steel by de-oxidation process in different furnaces including electric arc furnace, basic oxygen convertor, induction furnace, Bessemer process and other innovative melting techniques and then the re-smelted steel can be poured to form slab, blooming or billet as required and these semi-finished products are milled in to different cross -sections of finished products [8]. During the process of steel making, impurities such as silicon, manganese and carbon were removed in the form of oxides which either escaped as gas or formed slag.

The oxidation also raised the temperature of the iron mass and kept it molten. In view of [10] of steel making furnaces Bessemer converters cannot remove phosphorus efficiently from the molten steel and the nitrogen from the air made thus Bessemer steel is inherently fragile while the process of thermal efficiency was affected by the nonreactive nitrogen in air blast.

Following the poor property of steel products obtained from Bessemer steel making process [9-10] oxygen steelmaking process, a primary process in which the carbon-rich molten pig iron is made into steel by blowing oxygen instead of air through molten pig iron better was developed. This process may be carried out in basic calcium oxide and magnesium oxide refractory lined furnaces to low earth carbon content of the alloy and change it into low-carbon steel.

Secondary steel processing, is usually carried out in mini-mills and obtains most of its charge materials from scrap steel recycled from used equipment or by products of manufacturing. Direct reduced iron (DRI) is sometimes used with scrap to help maintain the desired chemistry of the steel [11].

According to [12] metal scrap recycling processing is the second step in recycling of metals. Scraps come from a variety of sources in many different forms and must be processed to facilitate efficient use. The primary roles of the scrap processor are to collect, sort, and grade, prepare, market and distribute scrap.

European Commission Joint Research Centre Institute for Prospective Technological Studies reflected their view on metal recycling that sorting is carried out following identification of the scrap. Sorting of scraps is done at the point of sale to the scrap dealers. Scraps are usually sorted based on the metal types. However, the sorting of scraps is done, most of the time, by visual inspection and not with any special devices. This requires a lot of skill and expertise especially in cases where the metals have degraded beyond recognition. In some cases, chemical processes are used in a wide range of metal scrap recycling industries as a means to separate scrap into its component metals. The chemical processes clean the scraps prior to using physical processes and also remove contaminants (such as paint) from scrap material. It also extracts selected metals from a batch of scrap containing many metal types [11].

It is seen in [11-12] that chemical processes may include high-temperature chlorination, electro refining, plating, leaching, chemical separation, dissolution, reduction, or galvanizing. The type and size of equipment they use depend on the types and volume of scrap available in the area and the requirements of their customers. Hydraulic shears, which have cutting knives of chromium-nickel-molybdenum alloy steel for hardness, slice heavy pieces of ship plate, railroad car sides, and structural steel into chargeable pieces, are also used. Baling presses are used to compact scrap into manageable bundles thereby reducing scrap volume and shipping costs.

According to researcher [11] further investigated that Ferrous scrap metals are magnetic and are often collected in scrap yards by a large electromagnet attached to a crane, sweeping across piles of scrap to grab magnetic objects.

Recycling can be conventional recycling process in which the process is carried out with a melting phase as a fundamental step. Large amount of metal loss occurs at the phases such as re-melting, casting and sawing. Though the conventional recycling process has the combustion of coolant or emulsion, pollution emission is much lower than the primary steel production process. The re-melting process costs less energy. While recycling, today, manufacturers have to consider ecological aspects [15] such as:

(1) Choice of ecologically sound materials; (2) Environmentally acceptable production methods; (3) Materials recovery and effective recycling programs; (4) Ecologically sound waste management.

As the conventional recycling processes (CRP) has been utilized for over 50 years, much improvement was made in this industry while some inevitable issues were found and concluded such as the recovery rate, emission control, melt energy cost and the quality of recycled metal.

Additional new scrap is generated after melting due to casting, cutting and rolling or extrusion processes. At last but the most important, a strategy to increase the demand of recycled steel is to increase the quality of the recycled materials [14]. In a typical recovery process, currently metal scrap recycling is becoming the versatile advantage both for developing and developed countries. Ethiopia as a developing country can be benefited from the recycling of metals in many aspects. For instance, reduction of foreign currency problem, increases metal product availability, reduces environmental pollution and economic development contributions for the country as well.

Authors [5] discussed that scrap smelting was conducted after scrap processing is terminated. It is vivid that scraps of low grade alloy steel which was wasted as a scrap and in the state difficult to use tends to be used by the metal producer factories and might be transported to the huge metal smelters working smelting process in a large amount. Author [6] disclosed that scrap recycling reduces greenhouse effect in such a way that the originally mined minerals emit more gas than that of the scrap. Energy saved using recycled materials can be revealed for each metal that for aluminum92%, and similarly, 90% for copper, 56% for steel. As it was observed At Akaki basic metal industry, a number of scrap metals were accumulated.

Moreover, the accumulated scraps of metal was not sorted in their variety, rather mixed in the intermingled manner, pollutes the land as well as the surrounding water flowing to the nearby community. Moreover, the scrap accumulation within the factory affects the economy of the county in general and Akaki basic metal industry in particular.

The accumulated steel scrap at Akaki basic metal industry was estimated to be about 400-500tons,whereas the value scrap after melting was found to be sold in 350-400birr per kg. and hence, recycling steel scrap which was accumulated in the compound of the industry can save maximum of (500*100*400) birr=200000000.00ETBirr or approximately 5000000 USD.

In general pollution is the global issue in the contemporary world. And hence, the initiation behind this study is to experimentally analyze the recycling properties of scrap steels available at Akaki Basic Metals Industry-Ethiopia through mechanical test analysis particularly tensile strength and hardness of the recycled product obtained from scrap, which in turn to reduce waste reduce environmental pollution such as land fill, water pollution, reduce foreign currency and increase the economy as well as identifying the properties of recycled steel. The government will use the findings as an input for proper law enforcement on the contemporary environmental pollution through the elimination of scrap by recycling. Finally, the management of Akaki basic metal industry will be benefited from this study in conducting decision concerning alloy steel recycling.

Even though, there are a number of metals types being processed at Akaki Basic Metals Industry-Ethiopia, this study focused only on the scrap of steel.

## 2. Materials and methodology

While conducting this study, a 30 kg steel scrap of non-identified composition type was purposively selected from the randomly dispersed scrap metal at Akaki Basic metals Industry compound. Experimental research design methodology with quantitative approach was then used to carry out this research. Experimental analysis was adopted to analyze the actual result while conducting the experimental analysis of steel scrap recycling since maximum of the research procedure was experimental and there appears a change in certain variables.

The characteristics(variables) analyzed was the overall procedures which includes, scrap identification, scrap melting by the resister furnace, molding and casting the molten steel scrap , spectrometer testing and finally the mechanical property testing of steel scrap.

The compacted and measured amount of scrap metal was melted in Induction furnace and a round ingot was produced by casting for testing purpose. Mechanical properties namely, tensile and hardness testing were conducted using universal tensile testing machine and rock well hardness testing machine.

Data for experimental study was collected in such a way that steel scrap was gathered from the ferrous scrap metal accumulation and identified based on the predetermined sample size. Accordingly, 30kg of the selected steel scrap as discussed above was melted up to the pouring

temperature particularly 1630°C then the liquid metal was poured into around type mold and a 42mmdiametr and 500mm length recycled cast steel sample was produced.
A sample for chemical composition analysis was taken from the already recycled steel sample and checked by spectrometer analysis. Tensile strength and hardness were conducted at Hibret Manufacturing and Machine Building Industry and at Akaki Basic Metals Industry respectively.
The procedure for data collection was physical observation of the accumulated scrap in the compound of the industry which helped to analyze the status of steel with regard to corrosion, cross-section of scraps, volume of scraps and other related phenomena and collecting and compacting as well as weighing of the sample was carried out manually and using magnetic separation method for ferrous metals. The observation also helped to determine sorting method of scraps for melting. The status of the foundry shop including pattern making area, mold making area, melting area and accessories required for casting were observed.

Observing the above areas first experimental activities were carried out including, melting. The selected sample was charged in to the induction furnace of laboratory size and allowed to melt up to 9hrs.On the process of melting Ferro silicon, Ferro-manganese and carbon were added to the melt based on melt sample analysis taken from the same melt at the intervals of melting for chemical composition balance. The sample analysis was carried out in the laboratory of the case industry using liquid type spectrometer. After checking the constituents balance and while the pouring temperature of steel reached to1630°C ,(where the melting temperature range for steel in this industry is from 1600°C to 1650°C for steel)the melt was poured to tea pot ladle and then to the pre prepared silica sand mold using round using wood pattern of 42mm diameter and 500mm length. Pattern removal was carried out manually since the pattern has had positive draft angle. Molding in this industry uses no bake system (resin and catalyst binding method).
Resin type used was Nitrogen free, furfural alcohol 80±3) free formal dehydrated with water content of maximum of 0.1%., storage life at 20°C one year, density 1.135gm/cc to 1.5gm/c, flash pint 68°C , less odors type that is processed in a continuous mixer.
The catalyst used has unlimited storage life (as told by the work shop expert) and its density at 20°C is 1.23upto 0.01gm/cc.
As observed from the industry document and existing experience of the researcher, solidification time of melt varies based on the weight of the metal, hence the solidification together with the cooling time for 10-200kg steel has been adapted at this industry as one day, thus the sample melted and cast for this research was allowed to fully cool to one day**.** Once the cast was cooled shaking of the mold was done using black smith hammer carefully and the cast, the gating elements and risers were removed by portable grainier and then cleaning was of the cast was done using brushes. A small sample was cut for spectrometer analysis as per the case industry standard for its composition analysis and another small sample was cut and prepared for hardness testing and a sample of diameter 40mm and length 240mm was also prepared for tensile strength testing.

## 3. RESULTS AND DISCUTION

### 3.1. Steel Scraps Observation Analysis Results

While conducting the observation of the scrap at Akaki Basic Metal Industry it was found that the accumulations of the metal scrap were huge amount dispersed with in the compounds of the industry. Moreover, the scrap accumulation was not sorted according to the type of metal (ferrous, on-ferrous). Scraps were corroded, mixed one another, sizes were different, and crosssections of different types of metals were observed in a mixed and disarranged manner. According to the information obtained from the industry management members and experts the scraps were collected from different industries, purchased from private owners, donated by different government organizations. The purchasing price of scrap steels from private dealers was 9ETBirr per kg. In general materials handling and storage mechanism of the industry was poor that one can underline as there is insufficient professionals in materials handling and storage system and no experts who deal with metallurgical behaviors of metal in the industry. The management of the industry is failed to give concern on storage and materials handling system. It is also possible to infer that the scraps may yield little due to the fact that maximum of the scraps were corroded and hence needs proper sorting and cleaning of scraps before melting.

**3.2. Steel scraps experimental analysis result**

As reminded in the methodology section above different experimental activities namely melting and casting of steel scrap, spectrometry analysis and mechanical testing that include hardness and strength testing were carried out at Akaki Basic Metals Industry and Hibret Machine Tools Industry.

Steel scrap melting was conducted at Akaki Basic Metals Industry. The sorted out and compacted 30kg steel scrap was charged in to an induction or resistance furnace capacity 100kg. The scrap was melted for a period of 9 hours with continuous evaluation of the chemical balance, especially Carbon, Ferro silicon and Ferro manganese content based on the laboratory analysis result and poured in to tea pot ladle at a pouring temperature of 1630ºC for further casting. Melting process carried out was displayed in figure1'a' and 1'b'. While melting it was observed that there were smoke and large amount of slag and dross. This was happened because of the quality of the charged steel which was totally corroded and was dirt as well as contaminated with grease, kerosene, oil and other contaminants. In this case cleaning and drying of charging scrap was essential measures to be taken by the industry and the researcher before melting. However the industry does not adapt these activities and there are no means of cleaning including chemicals. Only separation of ferrous metal scraps has been done in the industry using magnetic separation method. That was why steel scraps were sorted to melt and cast for this particular research.

Pouring to the already prepared mold was made slowly with the laminar pouring mechanism in order to control turbulence flow that causes entrapment of air, which consequently cause porosity.

a. Resister Furnace sat Akaki Basic Metals Industry

b. Steel Scrap Melting Process

Figure1: Melting furnace ‘a’ and melting process ‘b’

As mentioned above in the methodology section of this research the mold was prepared from silica sand following all requirements for casting steel including designing and making of gating system. Pouring was carried out manually using top pouring system in to the mold prepared for 42mm diameter and 500mmlength sample .No turbulence and webbing of liquid steel and spattering were observed. The cast steel rod obtained by recycling is displayed in figure2.

Figure 2: carbon steel recycled cast rod

As seen in the figure the surface of the cast is clean and the geometry is relatively good. This was because the pouring mechanism was proper and the pattern dimension was appropriate. However, because structure analysis was not the focus of this particular work the internal structure formed during solidification process was not considered in this research.

The chemical composition of the recycled steel scrap was conducted at Akaki Basic Metal Industry laboratory using TRECN solid spectroscopy of 4 mm minimum sample thickness handling type constructed for ferrous metal composition analysis. The spectroscopy used for analysis is displayed in figure3.

Figure 3: Spector meter tester used for composition analysis

Spectroscopic analysis conducted for recycled steel result is displayed in figure 4 that shows availability of 21 elements in the sample component. The work pieces was exposed to the spectrometer using probe handling device and the information was recorded through personal computer interfaced with the spectroscope as displayed in figure4 in the measure or grade result window.

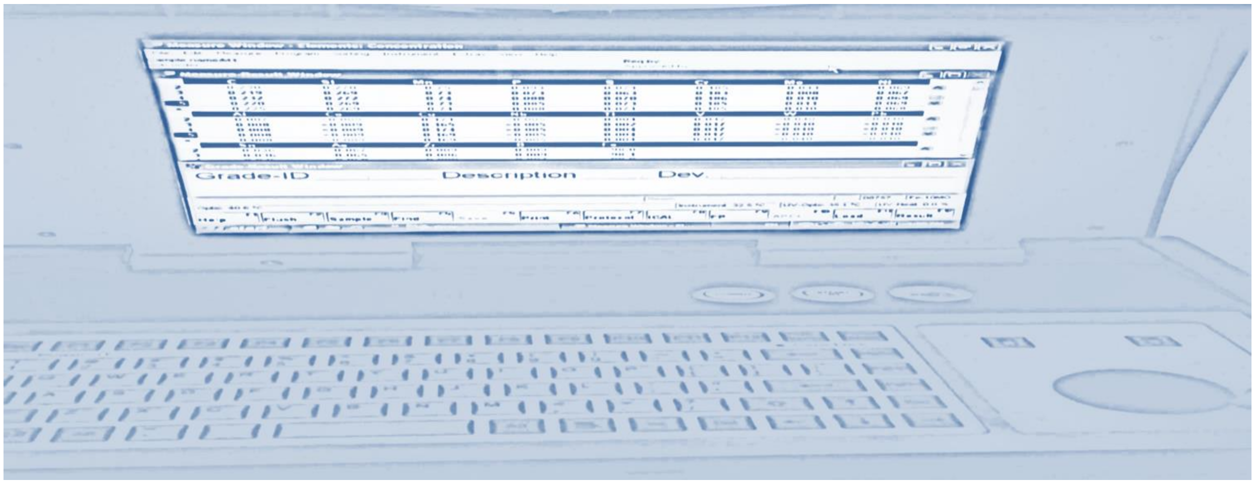
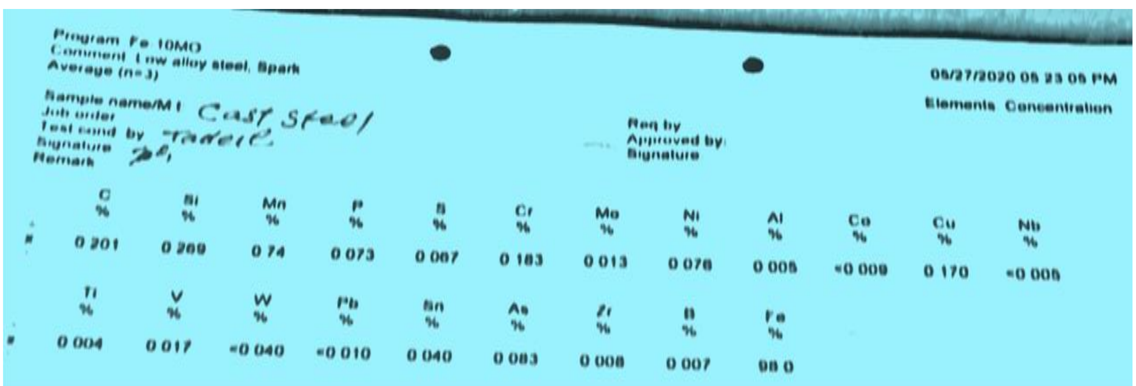


Figure 4: Spector meter testing display (measure window)

The ingredients include, C, Si, Mn, P, S, Cr, Mo, Ni, Al, Co, Cu, Nb, Ti, V, W, Pb,Sn, As,Zr, B and Fe at last. The above listed elements were shown with their corresponding concentration with in the sample under investigation on the above display unit of spectrometer tester. Figure5 shows the printable result of the test.



Program Fe 10MO
Comment Low alloy steel, Spark
Average (n=3)

05/27/2020 05 23 05 PM
Elements Concentration

Sample name/M I Cast steel
Job order
Test cond by Tadele
Signature
Remark

Req by
Approved by:
Signature

| C % | Si % | Mn % | P % | S % | Cr % | Mo % | Ni % | Al % | Co % | Cu % | Nb % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 201 | 0 269 | 0 74 | 0 073 | 0 067 | 0 183 | 0 013 | 0 076 | 0 005 | <0 009 | 0 170 | <0 005 |

| Ti % | V % | W % | Pb % | Sn % | As % | Zr % | B % | Fe % |
|---|---|---|---|---|---|---|---|---|
| 0 004 | 0 017 | <0 040 | <0 010 | 0 040 | 0 083 | 0 008 | 0 007 | 98 0 |

Figure 5: printout result of spectrometer test result

Table 1 shows the concentration of elements in available in the recycled steel cast from the scrap.

Table1: Concentrations of elements in recycled cast steel

| Chemical formula of the elements | C | Si | Mn | P | S | Cr | Mo | Ni | Al | Co | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Concentration % | 0.21 | 0.269 | 0.74 | 0.073 | 0.067 | 0.183 | 0.013 | 0.076 | 0.005 | <0.009 | |
| Chemical formula of the elements | Cu | Nb | Ti | V | W | Pb | Sn | As | Zr | Br | Fe |
| Concentration % | 0.170 | <0.005 | 0.004 | 0.017 | <0.04 | <0.01 | 0.040 | 0.083 | 0.007 | 0.008 | 98.2 |

As it can be seen from table1 the obtained product from recycled sample resembles low carbon structural steel. The carbon content of low carbon steel ranges from0.2-0.34% and the major elements including Mn and Si are within the range of such steel type [15-16]-The S and P concentration are also in the standard range used in the case industry. The total alloying elements of this steel reaches 1.74% and the balance is Fe. From the result one can infer that the obtained product leads the industry to recycle the scraps of steels accumulated in its industry and it is also possible to underline that the scrap has good recyclable property. Here it is essential to analyze the mechanical properties of such steel and confirm its recyclable property very well. Thus hardness and tensile property testing were selected. Other testing methods were not considered in the first case it was thought that the selected tests can indicate the impact resistance, twisting and bending properties, in another case there were no sufficient standard testing devices in the industry for such properties.

Tensile strength testing was carried out using universal testing machine at Hibret Machine Tools Industry –Ethiopia. Standard sample size diameter 40mm and length 240mm was prepared from the recycled cast metal using lathe machine as per the standard of the industry for the testing machine holding capacity. The tensile testing machine was interfaced with computer and the strength values as well as stress strain diagram was drawn directly on the display winnow of the computer.

Figure6: Universal testing machine at Hibret Machine Tools Industry

Test results obtained from the recycled sample is disclosed in table 2.

Table 2: Tensile strength test results

| Designation CZECH number | Tensile strength (Mpa) | Yield strength (Mpa) | Ductility% |
|---|---|---|---|
| 12024 | 380 | 310 | 25 |

From the table the values obtained for tensile strength, yield strength and elongation indicate that the recycled steel is in the category of plain carbon steel which particularly represents the strength of low carbon steel in which range of tensile strength reaches from 300-400Mpa and yield strength reaches to 350Mpa.Particularly elongation result strongly confirmed that the steel obtained has good ductility. The result approves also the workability properties of low carbon steel which again confirms the good recyclable property of steel scraps accumulated at Akaki Basic Metals Industry without proper materials handling system in a manner of wasting the economy of the country. Figure 7: shows the tensile strength diagram for the carried out test.

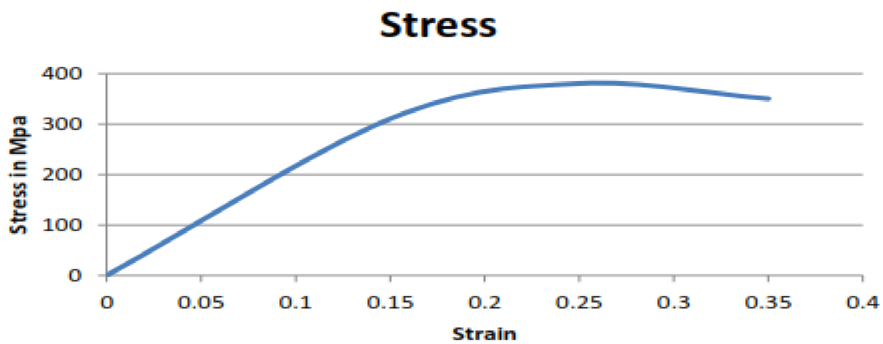



Figure7: stress strain diagram of the recycled steel sample

From the figure one can underline that such diagram is the property of steel.

The second mechanical property test that was carried out for the sample was hardness testing. The test was carried out at Akaki basic metals Industry using Rockwell hardness tester machine displayed in figure 8.Numberof tests were conducted in a well-polished sample cut from the recycled cast steel. The average result was RC=76.The result obtained is in the hardness range of low carbon steel and this confirms also the recycled steel can be useful for many engineering applications.

In general the conducted analysis results confirm that the steel scrap accumulated in the case industry can be recycled easily with the available devices and resources of the industry and consequently save the economy, reduce pollution of the area and creates job opportunity to the society.

## 4 Conclusions

This study was aimed at the experimental analysis of Recycling Property of steel scrap in the case of Akaki Basic Metal Industry. Through the observation in industry it was understood that large amount of steel scrap is accumulated in un sorted manner causing wastage and pollution of the environment. Changing theses scraps to useful product by recycling method was important issue. To do so experimental analysis using melting, casting, spectroscopic analysis of chemical compositions, mechanical property testing namely tensile and hardness testing were conducted. Based on the spectroscopic analysis it was possible to categorize the recycled steel as low carbon steel group. It was done based on the chemical composition result which particularly the carbon content was 0.21% and sulphur and phosphorus, manganese and silicon were in the range of low carbon steel group. Both mechanical property test results (tensile strength 380Mpa and hardness RC=76) also confirmed that this steel is in the group of low carbon structural steel. Based on this it is possible to conclude that the steel scrap stored randomly at Akaki Basic Metals Industry is recyclable and can save about 200 000000.00 ETBirr (around 5000000USD) thus a measure shall be taken by the industry to change this wastage in to useful product.

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