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Improving Mechanical Properties and Wear Resistant of Waste (High Strength Low Alloy Steels Cans) by Carburization using Genetic Algorithm

Hayder Al-Juboori, Nabil Al-Saffar and Saluh Jawad Hamza Al Nafie
Department of Metallurgical Engineering, College of Materials Engineering,
University of Babylon, Hillah, Iraq

Abstract: Recycling of iron and its alloys is the operation of re-melting iron so as to reuse in the production stage. High Strength Low Alloy Steel (HSLAS) is widely utilized in industrial applications such as in bridges, appliances, containers, buildings, highways tools and vehicles. This research deals with recycling of high strength low alloy steel from beverage cans by cans collecting, sorting and melting these cans to develop this processes, using casting technique for preparing alloy after the carburization to the base alloy so as to use in the fabrication of applications which need wear and corrosion resistance. The mechanical, physical and chemical tests carried out in this research involve hardness, surface roughness, wear, corrosion, microstructure, XRD and chemical composition analysis. The results showed that there were an improvement in mechanical properties of the alloy which was achieved by carburization. In comparison with the base metal, the hardness, improved by 152% with the carburization, enhance of compression strength and the surface roughness enhanced by 40%. Furthermore, the corrosion resistance and wear rate enhanced by 287 and 87%, respectively. Genetic algorithm was used to develop model for prediction and optimization of the hardness, surface roughness, wear rate and corrosion resistance after the carburization. According to the results obtained from practical tests, it has been able to identify the best alloy which is coded as A_{510} as well as determine the optimal alloy automatically based on the conception of optimization represented genetic algorithms which represented the chromosome number of 76, 19 and 16 for 1X, 2X, multi X-crossover, respectively. The mean absolute relative errors of the predict values of hardness, surface roughness wear rate and corrosion rate equal to 0.267, 0.311, 1.19, 0.047%, respectively as compared with the experimental values.

Key words: Corrosion, carburization, automatically, genetic, prediction, microstructure

INTRODUCTION

The recycling process of waste (metallic materials) and the usage of scrap are very important for the economic production of a steelworks (Torkar *et al*., 2010).

The process of recycling maintain energy as well as reduce raw material extraction and also, combats change of weather. Recycling of waste is better for the environs rather than landfilling or burning it. Today, there is a great possibility for councils to develop collection schemes and enhancing the benefits of recycling to the maximum extent by applying the best practice outlined in this briefing.

The best commonly scrap utilized and recycled of all the metals is iron with its refined product steel (ferrous scrap) and it is an essential activity worldwide. The products of iron and steel utilized in numerous structure and engineering applications such as in bridges, appliances, containers, buildings, highways tools and vehicles. The industry has developed for collecting old scrap (used and obsolete iron and steel products) and new scrap (ferrous scrap generated in steel mills and steel product manufacturing plants) because it is economically advantageous for recycling iron and steel by re-melting and casting into semi-finished forms to use in the fabrication of new steel products.

Certainly, the vital material of the modern technology focused the world is steel. Since, steel contains a class of over 2500 different grades presently made and utilized. The variation of properties of steel leading to wide range of uses. There are several options of combinations with respect to micro and macro structure, alloying elements, heat treatment and mechanical treatment processes, etc. (Janke *et al*., 2000) (Table 1). Micro alloyed steels or High Strength Low alloy Steels (HSLAS) are helped to offer well mechanical properties and high atmospheric corrosion resistant than conventional carbon steels. They are designed to meet specific mechanical properties

Corresponding Author: Hayder Al-Juboori, Department of Metallurgical Engineering, College of Materials Engineering, University of Babylon, Hillah, Iraq

Table 1: Chemical analysisof waste used in the current study

Elements	Percentage
C	0.06
Si	0.609
Mn	0.151
Cr	0.025
Ni	0.023
P	0.027
Al	0.124
V	0.008
Cu	0.024
Mo	0.01
S	0.066
Fe	Bal

such as a yield strength more than 275 MPa rather than to obtain a specific chemical composition. The chemical composition of a specific HSLAS may vary for different product thicknesses, so, as to meet mechanical property requirements (Skobir, 2011).

Recycling, the main purpose of this process was in the advance of maintainable system loop that can convert all the valuable resources which are burned or landfilled as waste materials into suitable products (Reuter *et al*., 2004).

MATERIALS AND METHODS

Material used for this study involves base alloy of high strength low alloy steel from waste and high strength low carbon steel from a coins. Chemical composition analysis was carried out for both materials ingot. Figure 1 shows the device used for chemical composition analyzing.

Preparation of samples: Firstly waste (high strength low carbon steel cans) have been melting by using gas furnacem type (Mario Dimaio-20122 Milano No. 5332, Italy) as shown in Fig. 2 after collecting, cleaning, cutting and squeezing so as to reduce its quantities as well to facilitate the smelting process. The gas furnace used in this study research in the field 0-3000°C.

Casting the molten in graphite mold after the removal of slag outside the molten and getting ingot of waste (low carbon steel ingot). Cooling the poured ingot in different cooling media (furnace, air, move air, oil and water).

Thereafter, the ingot of waste cutting into small disk samples with dimension diameter 20 mm thickness 3 mm using the machine lathe type (Harrison-England) before subjecting them for homogenizing process. In this research, homogenizing process is applying by raising the temperature of samples above 1100-1200°C with holding time 1 h and let the samples cooling in furnace reaching room temperature.

Heat treatments: Prior to heat treatment, samples with diameter 20 mm thickness 3 mm dimension were cutting

Fig. 1: Chemical composition analyzer used in this study

Fig. 2: Gas furnace used for melting

from the cast steel. Heat treatment was carried out utilizing an electrical furnace in research laboratory. Heat treatments had been done on samples included carbonizing.

Carburization: Carburization is a process of adding carbon to the surface. This is done by exposing the part to rich atmosphere of carbon at elevated temperature (nearly melting point) and allows diffusion to transfer the carbon atoms in the steel. This diffusion research on the principle of differential concentration.

The part that is to be carburized is packed in a steel container surrounded by granules of charcoal. The charcoal is treated with an alternating chemical such as Barium carbonate ($BaBo_3$) that promotes the formation of Carbon dioxide (CO_2). This gas in turns reacts with the excess carbon in the charcoal to produce Carbon monoxide (CO). Thus, $BaCO_3$ makes CO_2 available at an early stage of carburization and hence, it is called energizer. Carbon monoxide reacts with low carbon steel surface to form atomic carbon which diffuses into the steel (Torkar *et al*., 2010).

The case depth increases with rise in carburization temperature and time. The best carburizing temperature is 900°C for 4 h and let the samples cooling in furnace reaching room temperature that the steel surface absorbs carbon at a faster rate. In pack carburization it is difficult to control exactly the case depth because of many factors affecting it such as density of packing amount of air present inside the box, reactivity of carburizer, etc.

Physical, chemical and mechanical tests

Microstructure: This test includes grinding of surface samples has been done by utilizing study grits of alumina with various degrees of smoothness 180, 220, 320, 400, 600, 800, 1000, 1200, 1500, 2000, 2500 particle per square inch. A polishing process, using diamond and then the samples washing with distilled water and alcohol, the samples dried after each step using electrical drier. Thereafter, etching process using a reagent of Nital (2% HNO_3, 98% CH_3O) chemical composition that's by immersing the samples for 10-20 sec in the solution, so as not to burned and then washing the samples with distilled water and alcohol. Figure 3 shows the optical microscope used to see the microscopic structure of the samples in this research.

Micro hardness test: For hardness testing, suitable grinding and polishing processes were carried out with alumina study grits of 180, 220, 360, 400, 600, 800, 1000, 1500 before subjecting all the samples to this test. The test was conducted on Micro Vickers hardness device at the Metal Materials Lab., Babylon University as shown in Fig. 4 where a square-base diamond pyramid is falling down on the sample surfaces with a weight of 500 g for 10 sec. The hardness of all samples was recorded at an average of three hardness value at least taken from the surface of samples.

Wear test: The testing technique utilized for examining the sliding wear and the friction coefficient is pin-on-disc technique. In this test, the material removed from the samples that were calculated by weighing (weight loss). The samples prepared in this study and wanted to be tested for wear were set as a pin against a steel disc. The properties of steel disc that used for wear testing involve chemical composition of martensitic with minor carbides and austenite, mean surface roughness of (0.113 μm) and Vickers hardness of 405±14 HV. The test was performed at room temperature 25°C, utilizing loads 20 N, rotational speed of steel disc is 350 rpm, 5 different intervals of time 5, 10, 15, 20 and 25 min and sliding radius of 5 mm. Initially, this test includes measuring the primary weight of all the samples prepared in this study by using a sensitive balance and then placed in the wear device. The weights were placed in the device and the operation begin to start. After various time periods, the specimens were taken out and measured the weight then being replaced again in the device to complete the process. The wear rate is calculated according to Eq. 1 (Fig. 5) (Wang *et al*., 2006).

Fig. 3: Optical microscope

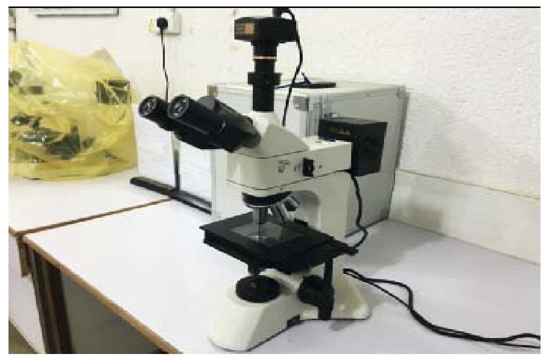

Fig. 4: Micro hardness measuring

$$R.W = \frac{\Delta w}{2\pi r n} \tag{1}$$

Where:

RW = Wear Rate (g/m)
Δw = Weight lost (g) which is the difference in weight of the samples before and after the test
r = The radius of the sample to the center of the disc (5 mm)
n = Disc rotational speed (200 rpm)
t = Sliding time (min)

Compressive strength test: Compressive strength is the capability of a material or structure to withstand loads. It

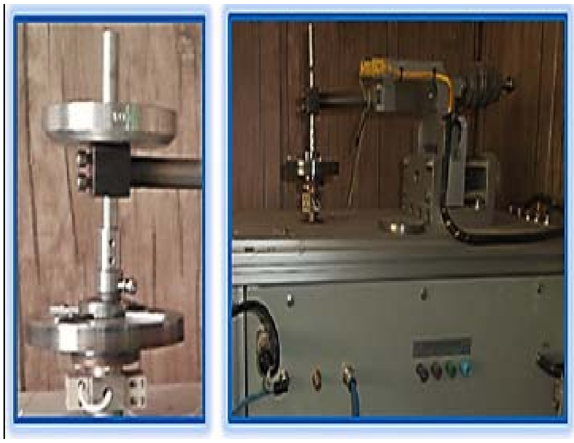

Fig. 5: Wear test device

can be measured by plotting applied force against deformation in testing machine. It is the key value for design of structure. In this test, samples were prepared in cubes and dimensions 10×20 mm. The test was run at a constant loading speed of 0.1 mm/min. The compressive strength is calculated by using the following equation:

$$\text{Compressive strength (MPa)} = \frac{\text{Max force (N)}}{\text{Cross section area (mm}^2\text{)}}$$

This test was conducted using samples for compressive alloy used in the search (A, B) before and after heat treatment so, as to know the stress that fail samples of the alloy listed and comparing between them. The test was conducted in Babylon University, College of Materials, Engineering-Laboratories metal section using device type (computer control electronic universal testing machine-model. WDW-200, serial No. W1124) as shown in Fig. 6 and maximum load capacity of 200 kN and the pulling speed (0.5 mm/min.

Optimization

Solution representation: The chromosomes in GA are arranged set of real values by utilizing visual basic language that represent the properties values of the resulting samples prepared in this study which be obtained by the laboratory tests. The chromosome length equal to (N) gene whereas the gene length is dynamic length. The length of first gene is the wear rate property and equal to five genes, second gene length is the hardness property and equal to one genes, third gene length is the surface roughness property and equal to one gene, fourth gene length is the current corrosion property and equal to one gene and fifth gene length is the cost property and equal to one gene.

Fig. 6: Compression testing device

Implementation: In GA, each operator does not depend on the other, therefore, there is no essential need to use all of these operators in a GA. The operator's choice or design can be influenced by the matter as well as the representation system employed. For an example, the operators designed for two strings cannot be straight utilized on strings coded either with real or integer number.

RESULTS AND DISCUSSION

Chemical analysis: A chemical analysis of the materials used in the current research shown in Table 2.

Microstructure: The initial microstructure of the base metal high strength low alloy steel with composition listed in Table 2 is shown in Fig. 7. The grain structure of the uncoated carbon steel surface is equiaxed as appears over the sample surface. The structure is ferrite and pearlite (α+P). The microstructures of carbon steel surface was observed after being etched for approximately one minute in an etchant Nital (Fig. 8).

Micro vickers hardness test: From the data results it observed that the variation of hardness values of all the samples prepared in this study is a function of cooling rate and type of heat treatment. The transformation from low to high cooling rate leads to increase the value of hardness. The high hardness values were recorded for the sample with (428). Figure 9 shows the effect of heat treatment of alloy without alloying elements on hardness of samples at different cooling rate. Hardness of samples

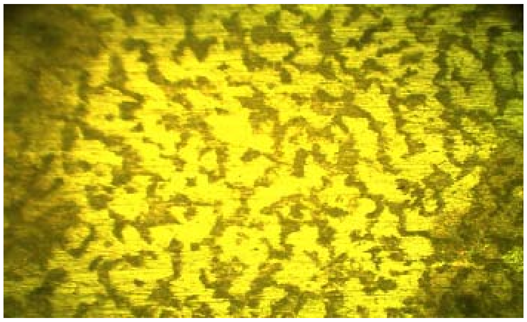

Fig. 7: Microstructure of waste sample

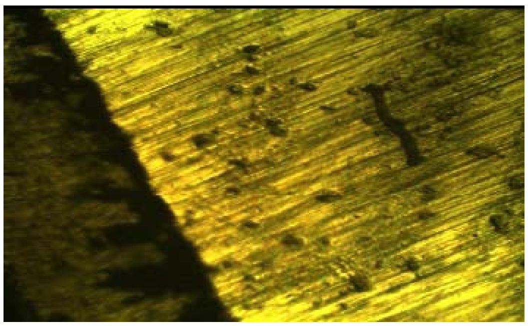

Fig. 8: Microstructure of carburization

Table 2: Chemical analysis ofcarburized waste used in the current study

Element	Percentage
C	0.103
Si	0.244
Mn	1.27
P	0.012
S	0.011
Cr	0.06
Mo	0.002
Ni	0.007
Al	0.015
Cu	0.026
Fe	Bal

increased with increasing cooling rate due to the formation of brittle structure from carbon atoms inside the lattice of iron which results from unable of carbon atoms diffusing.

Wear test: The pin-on-disc test after different periods of time for the heat treated and non-heat treated alloys is shown in Fig. 10 and 11. It is clear that the wear resistance proportional with hardness that increasing hardness leads to increase wear resistance.

Surface roughness: The surface roughness test is applied for all the samples prepared in this study of the measured samples. Figure 12 shows the variation of surface roughness of samples with respect to heat treatment. The results shows that the surface roughness of the alloys depends upon the bonding between different elements. Therefore, the it has not necessarily for decreasing or increasing surface roughness with varying cooling rates and type of heat treatment.

Compressive strength test: The compressive strength test is one of the important mechanical properties related to the maximum stress in that material. Figure 13 and 14

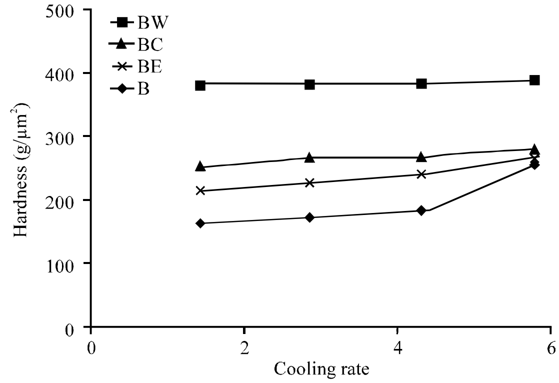

Fig. 9: Effdfdggfect of cooling rate on hardness with no alloying elements

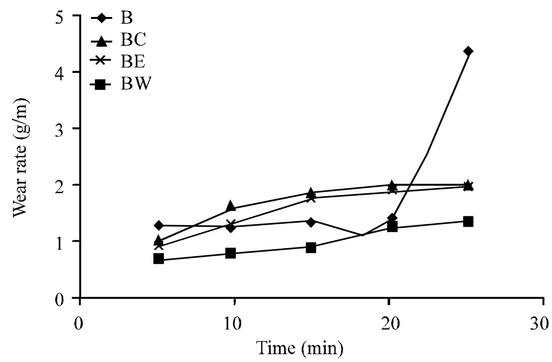

Fig. 10: Effect of time on wear rate of samples with no alloying elements

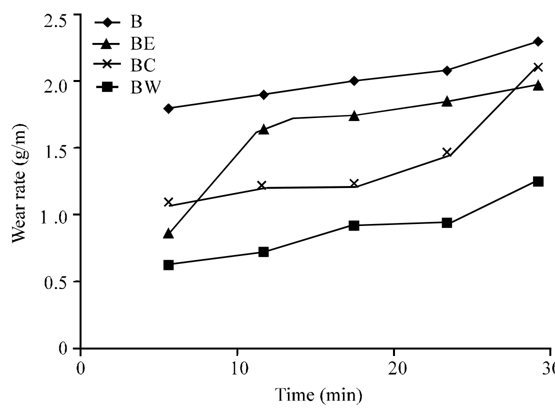

Fig. 11: Effect of time on wear rate of samples with no alloying elements

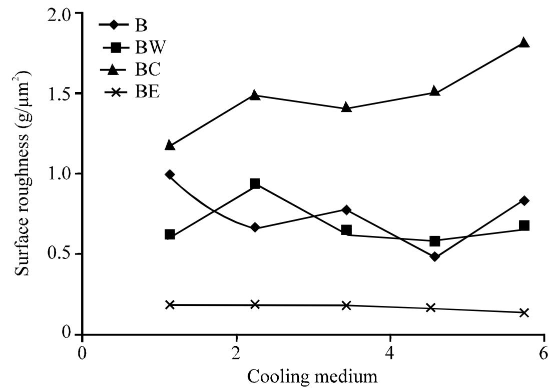

Fig. 12: Effect of cooling rate on surface roughness of samples with no alloying elements

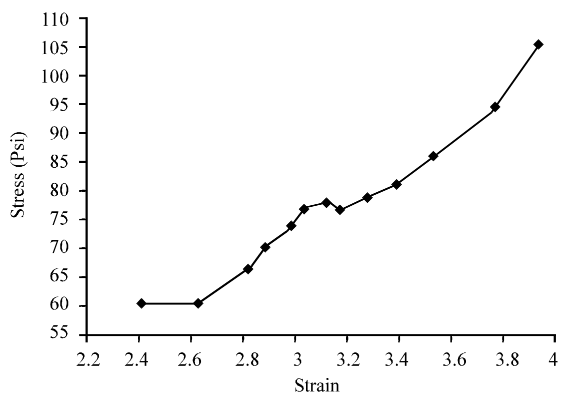

Fig. 13: The stress-strain curve of base metal

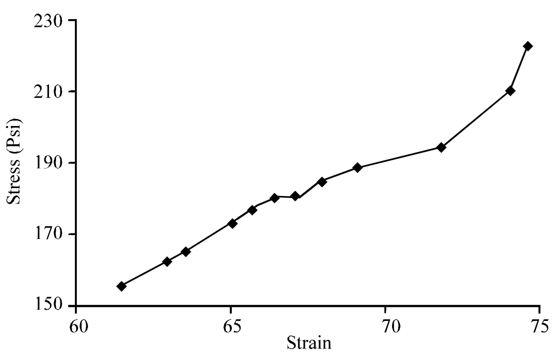

Fig. 14: The stress-strain curve of sample after the heat treatment

are showing stress-strain behavior after different periods of time for heat treated and non-heat treated alloys using extrapolation technique. It is obvious from Fig. 13 and 14 that the compressive strength increased with increasing cooling rate because increasing the hardness of samples.

Table 3: Results of the optimization algorithm represented GA for 1X-crossver operatorm compared to the experimental results

Features	Experimental	Optimization
F_1	0.01004×10^{-3}	0.01036×10^{-3}
F_2	0.05006×10^{-3}	0.05181×10^{-3}
F_3	0.4276×10^{-3}	0.41216×10^{-3}
F_4	0.4767×10^{-3}	0.46366×10^{-3}
F_5	0.5095×10^{-3}	0.50382×10^{-3}
F_6	415	416.11632691
F_7	0.0321	0.03228736
F_8	0.4177	0.41793466
F_9	180	183.85936247

Results of optimization: Table 3 results of the optimization algorithm represented GA for 1X-crossover operator compared to the experimental results.

CONCLUSION

The following conclusions may be drawn from the results of this research. However, they can be useful for future studies. Recycling is a way used to prevent accumulation of high waste quantity through their second processing, so as to utilize in the production of new materials. After heat treatment (carburization) of base alloy, the mechanical properties such as compressive strength, wear resistance, corrosion resistance and micro-hardness had been enhanced by 136, 57, 228 and 130 %, respectively.

RECOMMENDATIONS

It is recommended that further research should be undertaken in the following points. Studying the physical properties of the alloy prepared in this study such as electrical and thermal conductivity. Preparation of alloy by utilizing another way of casting such as centrifugal casting and sand casting then compare the results to stir method. Studying the effect of other heat treatment for example (annealing, normalizing and aging) on mechanical and physical properties of alloy.

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