Testing of Alternative Material for Production of Excavator Bucket Teeth from Scrap using Traditional Methods

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***Abstract*- Failure of the excavator bucket teeth is commonly overcome either by replacing with a new one which is too expensive or by welding the failure parts with metal that sometimes may have different properties from the original one, which may lead to imbalance cases. This study was conducted to test the modified welding method by fabricating alternative bucket teeth from available engine block scrap, using a sand casting process in a traditional foundry, operated by engine waste oil. The quality and properties of the two bucket teeth (Failure (F) and the Alternative (fabricated from scrap) (A)) were tested under laboratory and field measurements. Type of tests includes hardness, chemical composition, heat treatment, microstructure and field failure rate which had resulted in improving some of its mechanical properties such as hardness and wear resistance after practical application and comparison of the two samples in the study field which was tested after (2232 hrs for the failure) and (2016 hrs for the alternative) after 13 months each. According to the experimental results obtained from laboratory examinations and field measurements, the new alternative product has better properties than the failed one.**

***Keywords*- Alternative material, Bucket teeth, Chemical composition, Heat treatment, Hardness, Microstructure, Sand casting.**

I. INTRODUCTION

The bucket teeth are the main contacting part of the excavator, which comes first in contact with the soil while doing excavation at various sites. The excavator bucket teeth must bear heavy loads of materials like wet soil and rock. Excavator bucket teeth are subjected to the abrasive nature of soil particles when teeth acting to break up material and got damaged after had been subjected to severe abrasive wear. Generally, alloy steel is used to make an excavator bucket tooth and hard facing of some wear-resistant materials can be applied on the material of bucket teeth to improve its life against abrasive wear (Singla, et al., 2011).

The right selection of excavator bucket tooth and manufacturing types can be applied to enhance productivity. The cast teeth are made of austenitic ductile iron, heat-treated to obtain maximum wear resistance and impact resistance. They are made of medium carbon, chromium, and nickel; molybdenum steel that has high strength and toughness and has deep hardening performance. It can be an alternative to the standard forged teeth, high strength, self-sharpening and excellent wear resistance. Forged teeth are made of high-quality alloy steel, which can provide maximum resistance and impact after heat treatment and have a longer wear life than fabricated teeth and maintain excellent ductility. Forged teeth are made of high-quality alloy steel, heat-treated to provide maximum resistance and impact and have a longer wear life than fabricated teeth and maintain excellent ductility (http://www.colemanequipment.com).

Major existing papers reviewed various techniques in solving excavator bucket teeth failures, focused on excavator bucket teeth analysis, numerical software analysis and heat treatment of some material properties such as (modulus of elasticity, Poison's Ratio, Ultimate Tensile Strength, Bending Stress and Deformation) to find out the actual failures using different methods for solving the problems, depending on improving redesign, bucket tooth geometry and some mechanical properties (Kalpak, et al., 2015; Sathish, et al., 2017; Neeraj, et al., 2017).

On the other hand, other studies were conducted in improving wear resistance, tooth geometry and comparative analysis of materials based on some modified methods to give better wear resistance and long service life (Sathish, et al., 2017; Sabah, et al., 2017; Birendra, et al., 2016). Some studies have focused on enhancing wear resistance of bucket teeth using explosive hardening to ensure the required combination of properties of parts, after the hardening treatment for maximum durability of excavator bucket teeth, such as resistance, strength and ductility (Drago, et al., 2015).

However, most of these papers did not address any alternative materials from available material scraps utilizing local traditional methods, while some have conducted complex technical solutions not available in the study area of the Gezira Scheme or other similar remote rural areas where the failure of bucket teeth of working excavators is common due to several reasons. So this current work is different from the previous ones, in using the available alternative materials from scrap and applying local traditional methods.

Sand casting is the most widely used process in ferrous metals and non-ferrous metals because it is simple and easy to implement and has low waste and inexpensive, so it can be reused and could be suitable for traditional foundries. The process does not require much labor and has the same physical and mechanical properties (Ekey, 1958; Dada, 2015). The sand casting process involves many stages as shown in figure (1).

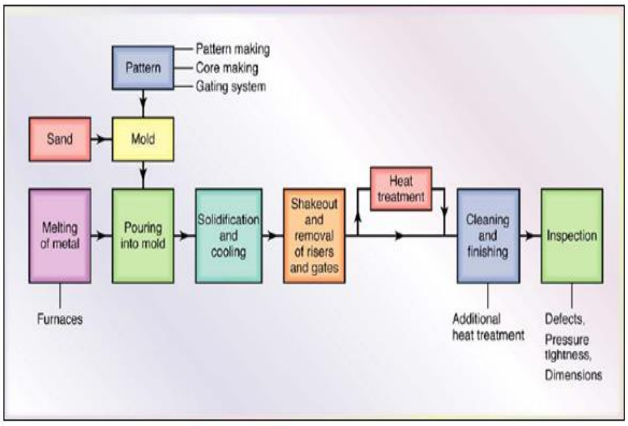

Fig 1. Stages of the sand casting process.
Source: (Kalpakjian, et al., 2014)

Heat treatment of metals is a heating and cooling operation to change their physical and mechanical properties, without letting them change their shape. For example, nodular cast irons which are one of the cast-iron types are subjected to normalizing, hardening, tempering, annealing and stress relieving heat treatment to achieve desired properties such as surface wear improvement and maximum ductility.

Usually, castings with high hardness and residual carbides are subjected to normalizing heat treatment to improve machinability without compromising the mechanical properties and commonly followed by tempering to reduce hardness and relieve residual stresses that develop when various parts of casting are cooled in the air at different rates (Davis, 1996; Rundman, 1991; Chandler, 1995).

Testing hardness has three main type methods (Rundman, 1991; Chandler, 1995):

- Brinell hardness: has an indenter of steel ball diameter, used on any metallic material with a wide range of test forces and sizes.
- Vickers hardness: has a diamond cone of 1350 include angle, used for all material and very accurate.
- Rockwell hardness: has an indenter of steel ball diameter (scale B) and diamond cone of 1200 include angle square (scale C), easy, quick to do, suitable for checking and read directly. Recently, Rockwell hardness machine had been developed to Electronic Rockwell hardness machine tester, which has dolphin nose indenter, quick, very easy and suitable for checking. The difference between this and other types is that it could be read directly from a digital screen, multiple test force generation, real-time electronic test and automatic preload.

The chemical composition and microstructure of steel castings determine their mechanical properties.

Likewise, they are determined according to the material specifications of each type or grade of material.

Metallurgical structure and carbon content are the main contributors to the overall performance of different carbon steel materials. Materials classified as carbon steel may also contain small amounts of other elements such as chromium, nickel, molybdenum, copper, vanadium, niobium (ni), phosphorus and sulfur.

Each element added to the basic composition of iron will have some impact on the final properties of the material and how the material reacts to the manufacturing process. Alloy additives are responsible for any differences between various types or grades of carbon steel (Flenner, 2007; Bramfitt, 2007).

II. MATERIALS AND METHODS

The objectives of this work were to fabricate and test alternative material for excavator bucket teeth production from alternative material scraps, utilizing the traditional method and also to conduct laboratory examinations on its heat treatment and field measurements on the new alternative product and the old failure one.

1. Fabrication of Alternative Product:

The alternative bucket tooth was produced by creating the mould, utilizing a sample of CAT style with model number part, 1u 3352 as mould shape, using sand casting process, reversing shape of the part needed, using alternative material of engine block scrap. The mould was made from refractory sand that was brought from Blue Nile River shore not far away from the local traditional foundry.

The engine block scrap was heated in an oven which was operated by engine waste oil until it was melted; then the molten scrap was poured into the created mould cavity through the outlet pipe of the waste oil from the tank. The molten liquid scrap of the engine block had been taken the shape of the cavity, which was the shape of the alternative tooth needed. It had been cooled and waiting until it was solidified and removed from the mould and conducted a finishing process on it.

2.Testing for Heat Treatment and Hardness:

To obtain the required properties without changing the shape, the alternative fabricated bucket tooth was normalized and heat-treated in a salt bath at 800o C for 30 minutes and then cooled in air. Hardening was conducted in the same salt bath at 800o C, soak for 20 minutes, in oil for 5 to 10 minutes until cooled. The temperature was maintained with the aid of a thermostat that was used to control the salt bath temperature and then reconstituted in hot water. Hardness was checked in an electronic Rockwell hardness machine at the central laboratory of the Yarmouk Industrial Complex, Khartoum, Sudan.

3. Testing for the Microstructure of an Alternative Sample:

The sample of heat-treated alternative bucket tooth (A) had been cut, using a cutting machine (METKON), then prepared and cleaned, using preparing machine (Nikon) for microscope and then was polished manually using a polishing disc with 1µm abrasive particles and mounted on a mixture of 100 ml picric acid, 2 ml Tepol and 10-12 drops of hydrochloric acid and mixed in glass container filtered twice. The sample was immersed in the mixture, kept for ten minutes and then rinsed in water with high agitation, held under pouring water for a while after cleaning with ethanol.

The optical microscopic examination was carried out for microstructure at the central laboratory of the Yarmouk Industrial Complex, Khartoum, Sudan.

4. Chemical Composition Analysis:

The Failure and new alternative samples of bucket teeth had been tested at a laboratory for determining chemical composition analysis using Spectrometer PORT, GNR Analytical instrument. For chemical analysis, the parts should be milled and ground to face so that the joystick of the machine is placed on a flat surface and the start button of the machine is pressed. Readings were taken directly from the machine screen.

5. Experimental Length Loss:

The working field period of the old failure bucket tooth, which was connected onto a short jib excavator, was operated from the 6th of January, 2017 to the 1st of January, 2018 and by calculating all period, it was found to be 248 days or 2232 hours per 13 months during the working study life. On the other hand, the working field period of the new alternative bucket tooth has extended from the 24th of December, 2018 to the 1st of December, 2019 and by calculating all period, it was found to be 224 days or 2016 hours per 13 months as working study life under the same soil structure content of the Gezira Scheme (sand 30%, silt 45% and clay 25%). Experimental length loss (LL) of the failure (F) and alternative (A) samples had been measured and calculated by using digital Vernier within the field study duration, before which it was the original length (OL) and after which it was failure length (FL). Field experimental working hours per day are (9 hours) according to the Ministry of Irrigation and Water Resource (MIWR), Sudan.

III. RESULTS AND DISCUSSIONS

1. Heat Treatment and Hardness Result:

The investigated failure (F) and alternative product samples (A) of bucket teeth were tested and measured for hardness. The alternative sample shows a better value than the failure one as shown in figure (2). An alternative sample of fabricated bucket teeth exposed to normalizing heat treatment was checked for hardness and was HRC42. Figure (2) shows hardness values of the heated alternative sample (Ah) compared to failure (F) and alternative (A).

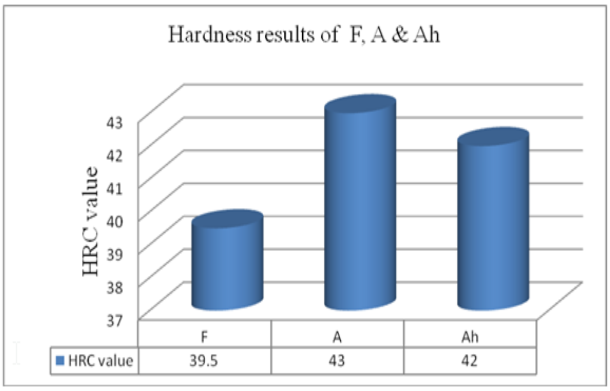

Fig 2. Hardness Test Result.

2. Microstructure Examination Result:

After checking the microstructure of the alternative bucket tooth sample, there was nodular graphite in the photomicrograph, which is an indicator of ductile cast iron, as shown in figure (3).

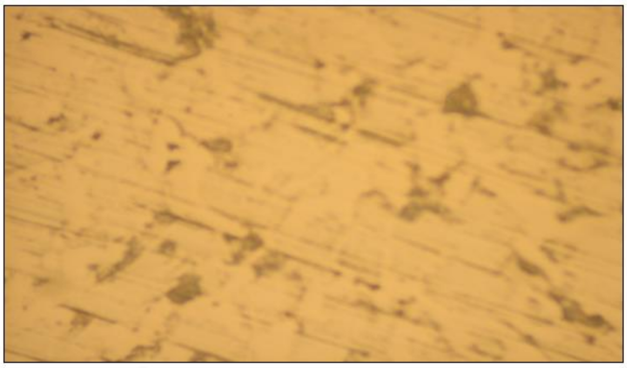

Fig 3. Micrograph of Nodular Graphite.

3. Chemical Composition Test Results:

The failure and alternative samples of bucket teeth had been tested at the laboratory to determine the chemical composition using spectrometer equipment. The analysis has resulted in manganese steel for the failure sample which has contained less than 2.0% of carbon (0.277), where the resulted alternative cast iron has contained more than 2.0% of carbon (2.725) as shown in figure (4).

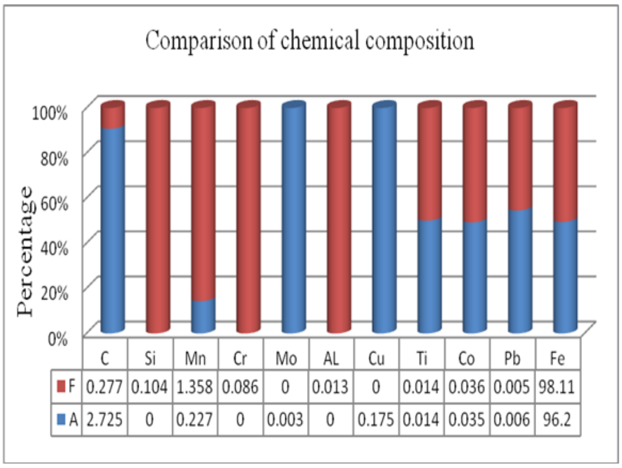

Fig 4. Chart of Chemical Composition Test Results.

4. Experimental Length Loss:
The results of experimental length loss (LL) of the failure (F) and alternative (A) samples after had been measured and calculated after the field study duration has shown a decrease in length loss of alternative sample compared to the failure one, as shown in figure (5). Therefore, the alternative sample has better wear resistance than the failure one.

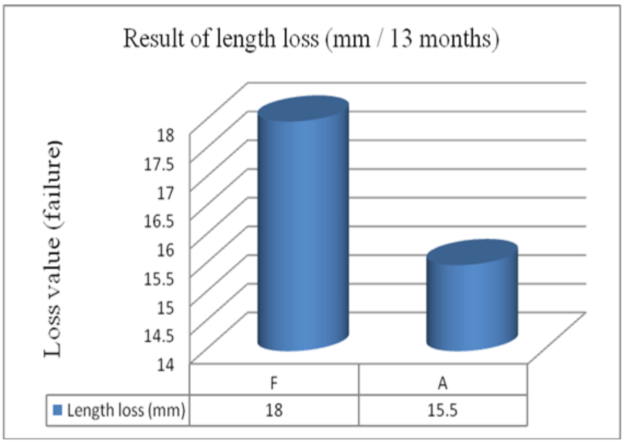

Fig 5. Length Loss Result.

IV. CONCLUSIONS

This work focuses on solving the failure of excavator bucket teeth by fabricating an alternative one, which is suitable for traditional foundries using the sand casting process, which is simple, economical, has less waste and requires less labor. It can be remoulded and reused and the alternative products have better properties than the failure products.

Also, it can be developed and expanded, including repairing sand foundries in local traditional foundries to meet the needs of the local market by recycling available waste materials, thereby localizing the manufacturing of excavator bucket teeth.

V. ACKNOWLEDGMENT

The authors would like to thank the staff of the central laboratory of Yarmouk industrial complex, Khartoum, Sudan for their help during laboratory work and thank extends to colleagues in the Ministry of Irrigation and Water Resources, Sudan.

The authors would like to express their gratitude to Dr. Nuru Adgaba Mohamed for his constructive critiques.

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