March 2010

Design, Fabrication, and Testing of a Fixture for use in the Carburization of Steel

Nicholas J. Contrino
Worcester Polytechnic Institute

Design, Fabrication, and Testing of a Fixture for use in the Carburization of Steel

A Major Qualifying Project Report

Submitted to the faculty

Of

Worcester Polytechnic Institute

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

Submitted By: Nicholas J Contrino

Advisor: Professor Sisson

Date: 3/15/2010

Abstract

In the scientific process, the proper equipment is essential for collecting quality data. This project was to design and fabricate the fixturing for use in experiments to determine the effects of surface roughness on the carburization of steel alloys. Potential contaminates on the test samples were removed using a self contained cleaning system. Afterword the samples were carefully transported and attached to a carburizing fixture of unique design. This fixture was designed and manufactured to be compatible with preexisting commercial equipment and tested to withstand the stresses of the carburization process. The carburizing cycle completed without failure, the samples were removed and successfully prepared for analysis.

Acknowledgements

Professor Sisson

Olga Karabelchtchikova

Bodycote

Stafford Specialty Wire

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1.0 Introduction

Fixturing or racking of steel parts for carburizing heat treatment is very important for the quality of the heat treated parts. The fixture must provide support for the part or sample and allow gas flow around the part. This is particularly important for experimental work on these heat treatments. [2]

It was the task of this project to design, fabricate and test a fixture to support sample test pieces for the series of gas carburization experiments conducted by Olga Karabelchtchikova. [10]

Methods for testing this process have not been specifically outlined in the standardized literature so a novel methodology had to be devised and materials selected to form a proper test. As the experiments tested the effect of surface roughness on the carburization of various steels, different grades of roughness were required. This raised further questions, including the degree of roughness for the samples, the methods used to measure roughness, and the number of grades to test. An entire operation had to be engineered for making the samples, cleaning the samples, carburizing the samples, and then studying the samples. [10]

1.1 Challenges

Any design of the experiment must address the following issues:

- Contamination - The main challenge of this project was to maintain the integrity of the samples by preventing the introduction of foreign materials. Due to the small sample size compromising any of the samples would render the experiment invalid, yielding inaccurate results or test pieces that could not be used.

- Damage - Numerous opportunities for potential damage to the samples existed in every stage of the process, and had to be managed:
    - Production – An error in the machining could occur during the initial production.
    - Attachment – During attachment and removal the samples could be damaged by the mechanism that holds them in place.
    - During Testing – The samples could collide with each other or a part of the set-up.
    - Transport and Storage – The integrity of the samples could be compromised before or after the carburization process.

  Any damage to the surface of the samples could result in deviations from the desired roughness, the variable under study.

- Repeatability – The experiment had to be set up matching the design constraints provided by the experimenter and allow for repeatability by ourselves and other colleagues in the field.

1.2 Expected Results

The samples would be created to specifications, set up properly, and make it through the experiments uncompromised. The fixtures would not fail or introduce contaminants [3]. The design would maintain the rigor of the scientific experiment and yield quality specimens for study.

2.0 Background

Carburization is the process of diffusing carbon into the surface of a workpiece at high temperature [5]. Typically the composition of the workpiece is a low carbon steel or alloy. The additional carbon grants beneficial physical, mechanical, and chemical properties to the surface of the workpiece. The core of the workpiece will remain unchanged and will retain its original desirable qualities. Carburization is also referred to as case hardening. [14]

2.1 Method

Carburization of low carbon steels involves the heat treatment of the surface of the workpiece using a gaseous, liquid, solid, or plasma source rich in carbon. Workpieces are placed in a furnace and heated for a length of time in the presence of the carbon source. Modern techniques use carbon-bearing gases or plasmas as the source, most often carbon dioxide or methane. Primary factors involved include the concentration of carbon in the gas or plasma, the temperature of the furnace, and the length of time of the heat treatment. The heat and time factors must be carefully controlled to yield the best result for the surface without affecting the core of the material adversely. [15]

The most common form of carburization is gas carburization. The workpieces are placed in a furnace and surrounded with a high carbon releasing atmosphere. This atmosphere is often composed of multiple components and must be carefully controlled such that the high carbon potential is maintained. The close monitoring of this atmosphere is also important in avoiding negative side effects, such as surface and grainboundary oxides. This will often require a separate piece of equipment connected to the furnace with the responsibility of monitoring and maintaining this atmosphere within operational parameters. [5]

The type of equipment used varies according to the size and quantity of the workpieces, and the desired depth of diffusion. Most often gas carburizing is used for large workpieces with the main goal to insure maximum contact between the surface of the workpiece and the carbon source. In gas carburizing the workpieces are often supported in mesh baskets or suspended by wire. Typically the materials that are carburized are irons and low-carbon alloy steels. It is important that the workpiece surface be free from contaminates, such as oil oxides or alkaline solutions, which can interfere with the diffusion of carbon into the workpiece surface.

2.2 Technology

Steels and other metals are formed from atoms arranged into a metallic crystalline lattice. The carbon atoms diffuse between and into the crystal structure. At lower temperatures carbon atoms remain between the metal crystalline matrix, this causes lattice strains and strengthens the surface of the workpiece. This is called solid solution strengthening and improves corrosion resistance while increasing the metal’s hardness. At higher temperatures carbon atoms react with the metallic atoms in the crystal structure and are introduced into the matrix forming ceramic carbides, which are very hard particles that resist abrasion. This is called precipitation strengthening and also greatly improves the hardness of the workpiece’s surface.

There are different types of elements or materials that can be used to perform this process, but mainly consists of high carbon content material. A few typical hardening agents include carbon monoxide gas, sodium cyanide and barium chloride. In gas carburizing, the carbon monoxide gas is usually given off by propane or natural gas. [5]

2.3 Effects and Benefits

Carburization has a number of benefits associated with the physical, mechanical, and chemical changes it makes to a workpiece. The physical changes include an increase in grain size which will affect its creep properties. Because of this a change in volume may occur. The mechanical benefits include increased surface hardness, increased wear resistance, and increased fatigue and tensile strengths. The alteration of the workpiece's chemical composition, with the introduction of additional carbon atoms, will also benefit its corrosion resistance. [9]

Because case hardening only affects the surface of the workpiece, the case and core of the finished piece have different properties, and this difference is more pronounced in steels that have low-hardness. When an application requires these benefits in the case, yet still demands an overall toughness and ductility from the core, carburization is a cost effective and efficient solution. Even with its increased complexity, gas carburizing has become the most effective and widely used method for carburizing steel parts in large quantities. [14]

3.0 Design Methodology

3.1 Needs and Constraints

The test had to perform on sufficient samples for statistical testing. Variability in the roughness of the samples was also required to test the effects of different degrees of roughness on the carburization process.

To ensure the validity of the experiment, the conditions of the samples had to be standardized and controlled. No foreign substances or unaccounted surface features should be introduced to individual samples. The samples must be stored in a climate-controlled, sealed environment. Before the carburization process, the samples must be thoroughly cleaned to remove any possible foreign substances.

The machining must be inspected so no errors are introduced. The samples must he held in place with a method that permits attachment and removal with no damage. The samples must not collide with each other or any part of the set up. It must be possible to transport and store the samples before and after the carburization process in a way that maintains their condition.

For repeatability, the samples should be machined from commonly available, standard AISI/SAE steel grades [6]. The samples must be of appropriate dimension in order to measure the case depth produced by the two hour carburization duration used by Bodycote. The samples have to be held in a fixture that fit the grate sizes used in Bodycote furnaces. As these grates were uniform, the fixture had to be adjustable to fit any grate.

All materials and construction processes of the fixtures must be designed in order to withstand the stresses produced by the furnace.

3.2 Ideas/Analysis/Selection

The objective of the experiment was to test the carburization performance of several steels with varying degrees of surface roughness. The experimenter chose the types of steel we would be using based on several factors, including availability and replicability. The samples had to be thick enough such that the carburizing effect would not penetrate all the way through. The available bar stock was sufficient for selecting the types of steel. We used round bar stock, as it was readily available and had no corners to effect the ratio of surface area to volume which could affect carburization concentrations.

In order to simplify the process and eliminate variables we decided to clean the samples before the carburization process. The requirements for the cleaning system were outlined by the experimenter and had to make use of available resources, such as the cleaning bin. This introduced additional constraints such as the opening size on the top of the cleaning bin. Since the total number of samples was too many to fit on the cleaning fixture at one time the cleaning process was performed in two batches. The samples were suspended by wire such that all sides could be properly cleaned. The best way to achieve this was to drill a hole in the sample and threaded a wire through. Then the samples could be suspended from the cleaning fixture. This method also proved to be beneficial for the carburizing process. [4]

After meeting with the carburizing company it was clear that the cleaning fixture would not suffice for the carburizing process. The company's standard process was to put their workpieces in baskets before placing them in the furnace. This method would not work with our desired process, as it could introduce variation into the carburization process. We decided to suspend the samples from wires in a similar way as the cleaning process. We could use the same wires, since they had also been cleaned, for the duration of the experiment. To prevent the samples from shifting or hitting each other I designed and fabricated a custom carburizing fixture.

The carburizing fixture was attached to the bottom of the basket and had sufficient cross sections and adequate spacing to attach the samples safely and securely. The size of the fixture was based on the basket size; it needed to be slightly smaller than the bottom of the basket. This was due to the fact that the baskets were stacked, so the size of the fixture had to be smaller than the base of the baskets. The material of the fixture was a low carbon steel, as it was readily available and could withstand the stresses involved in the carburizing process. The dimensions were sufficient to hold the carburizing system and samples, but not have any unnecessary weight added that would make it difficult for the brackets to support the whole system.

The way the fixture was attached depended on the basket rods size, shape, and distribution. The brackets could wrap around the basket rods and attach to the carburizing fixture itself. While fewer brackets provide enough of a safety factor, I would use nine brackets for additional security. This included a center bracket that could better distribute the stresses on the fixture than if it were only attached at the corners.

After the samples were carburized the wires would be brittle enough, from the heat treatment, and could be snapped off without harming the samples. This would be more efficient than unthreading the wire, and would have less of a chance of scratching the samples.

4.0 Final Design

4.1 Samples

The samples to be tested were of a size determined by the experimenter [10]. The samples were cylinders machined to 3.125cm in diameter, 1 cm in length, and with a hole through which a wire could be inserted to allow the samples to hang freely while being carburized. The faces of each sample were prepared according to the roughness specified (Table 1).

Table 1 - Surface Finishes of Samples

Table 1. Surface finishing operations. Sandblasting	Particle size diameter - 0.09 cm , pressure 0.78 MPa, angle 90°
Wire brush - 1	2000 rpm, 25.4 cm/min feed rate
Wire brush - 2	3000 rpm, 5.08 cm/min feed rate
SiC: 120 grit	120 grit, average particle size - 116 µm
SiC: 800 grit	180 grit, average particle size - 12.2 µm

[10]

These samples were then tagged by inscribing the metal type and roughness, cleaned, mounted in the carburizing fixture, carburized, and then cut and etched for analysis.

4.2 Cleaning System

A cleaning fixture (Figure 1) was designed and constructed to hold all of the samples in place securely during cleaning without contacting each other or any part of the cleaning apparatus. The fixture suspends the samples at a level in the center of the solution, with enough clearance from the bottom, sides, and other components, and is easily introduced and removed from the cleaning system. The cleaning fixture was cleaned separately using the same solution as in the cleaning systems before being introduced into the system with the samples.

Figure 1 - Cleaning System

The process was carried out in a hexagonal plastic bin large enough to accommodate the cleaning solution, a heater, an agitator, the cleaning fixture, and samples. The cleaning system components were thoroughly cleaned and dried prior to introducing the solution. Enough cleaning solution was added to the bin to completely submerge all of the samples. The samples were attached to the cleaning fixture by wire, which would then remain attached through the remainder of the experiment so that the samples would not be chipped or scratched in the removal of the wire or replacement of a new wire (which would require separate cleaning). The fixture was then inserted into the bin, submerging the samples.

During the cleaning process, the heating rod maintained the temperature of the cleaning solution within a specified range, and the mixing device agitated the solution to prevent stagnation and ensure thorough removal of contaminants. Once in the system for the recommended amount of time, the samples were carefully removed and prepared for the carburizing portion of the experiment. The cleaning fixture did not need to be as durable as the carburizing fixture as it would not be put through the stresses of the carburizing process. It was fabricated by welding thin straight rods from 1018 steel (which would not react with the solution) into a simple grid design. The corners of this cleaning fixture were attached to two beams with adjustable wires to allow it to be suspended at an appropriate depth in the solution.

The cleaning system was designed to clean half of the samples at one time, requiring two cleaning cycles but allowing the bin and fixture to be half the size. After the first cycle, the samples were removed and placed in plastic bags to avoid contamination. The entire system was flushed in preparation for the second cycle. All the components were re-cleaned, new solution was introduced, and the procedure was repeated for the second half of the samples.

4.3 Carburizing Fixture

The carburizing fixture (Figure 2) was designed to fit inside of the crates used by Bodycote for the carburizing process. As the samples would hang freely, the carburizing fixture would be attached to the crate from the bottom by brackets. The strength required to support the carburizing fixture and samples through the duration of the process dictated the number and placement of brackets. Additional brackets were included to further reduce the chance of failure. [3]

Figure 2 - Carburizing Fixture Cage

The brackets (Figure 3) were fabricated from welded slits of 1018 steel. The carburizing fixture itself was machined out of a single sheet of 1018 carbon steel [6]. Though stress analysis data of steel at such high temperatures was limited, it was possible to calculate that the brackets would be well within safety tolerances to hold the carburizing fixture and samples in place for the duration of the carburizing process. [7]

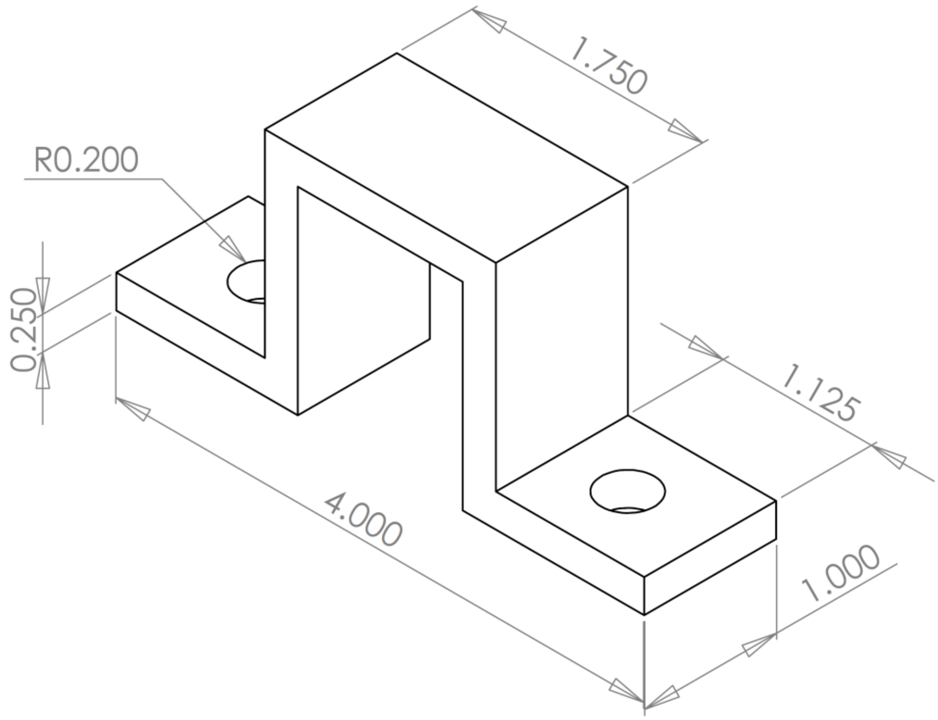

Figure 3 - Fixture Bracket w/ Dimensions in Inches

Stress Analysis of Bolts & Brackets

Given:

$S_{ys} := 250MPa$ $n_h := 18$ $n_{br} := 9$ $W_{tot} := 28.6lbf$

$d_{bolt} := \frac{3}{8}in$ $t_{br} := \frac{1}{4}in$ $w_{br} := 1in$

Equations:

$SF = \frac{S_{ys}}{\sigma}$ $\sigma = \frac{F}{A}$

Solve:

$A_{bolt} := \frac{d_{bolt}^2}{4} \cdot \pi = 0.11 \cdot in^2$ $A_{br} := t_{br} \cdot w_{br} = 0.25\,in^2$

$F_{bolt} := \frac{W_{tot}}{n_h} = 1.589lbf$ $F_{br} := \frac{W_{tot}}{n_{br}} = 3.178lbf$

$\sigma_{bolt} := \frac{F_{bolt}}{A_{bolt}} = 0.099MPa$ $\sigma_{br} := \frac{F_{br}}{A_{br}} = 0.088MPa$

$SF_{bolt} := \frac{S_{ys}}{\sigma_{bolt}} = 2.52 \times 10^3$ $SF_{br} := \frac{S_{ys}}{\sigma_{br}} = 2.853 \times 10^3$

Since the crates were not completely uniform, the fixture had to be adjustable. The final design of the carburizing fixture (Figure 4) includes a pair of slits at each end to form tracks that allow for up to three brackets per end, as well as a pair of slits at each side that allow for one bracket each. The grid had to be thick enough that it would not fail under its own weight, but not susceptible to creep or stress failure. Below is the calculation for a worst case scenario of all the stress applied to a single section.

Stress Analysis of Carburizing Fixture

Given:

$S_{ys} := 250MPa$ $W_s := 0.22lbf \cdot 30$ $d_x := 24in$ $d_y := 0.25in$ $d_z := 0.4in$

Equations:

$$SF = \frac{S_{ys}}{\sigma_{tot}} \qquad \sigma_{sh} = \frac{F}{A} \qquad \sigma_{bnd} = \frac{F \cdot d \cdot y}{I_{xx}} = \frac{F \cdot d \cdot 6}{b \cdot h^2}$$

Solve:

$$\sigma_{bnd} := \frac{W_s \cdot \frac{d_x}{2} \cdot 6}{d_z \cdot d_y^2} = 131.056MPa$$

$$A_{sh} := d_y \cdot d_z = 0.1 \cdot in^2$$

$$\sigma_{sh} := \frac{W_s}{A_{sh}} = 0.455MPa$$

$$\sigma_{tot} := \sigma_{bnd} + \sigma_{sh} = 131.511MPa$$

$$SF := \frac{S_{ys}}{\sigma_{tot}} = 1.901$$

For extra support, the center of the fixture incorporated a pair of semicircle slits allowing a center bracket to be adjusted via rotating to attach to intersecting bars of the crate [11]. The corresponding bracket would be greater in length to accommodate this feature.

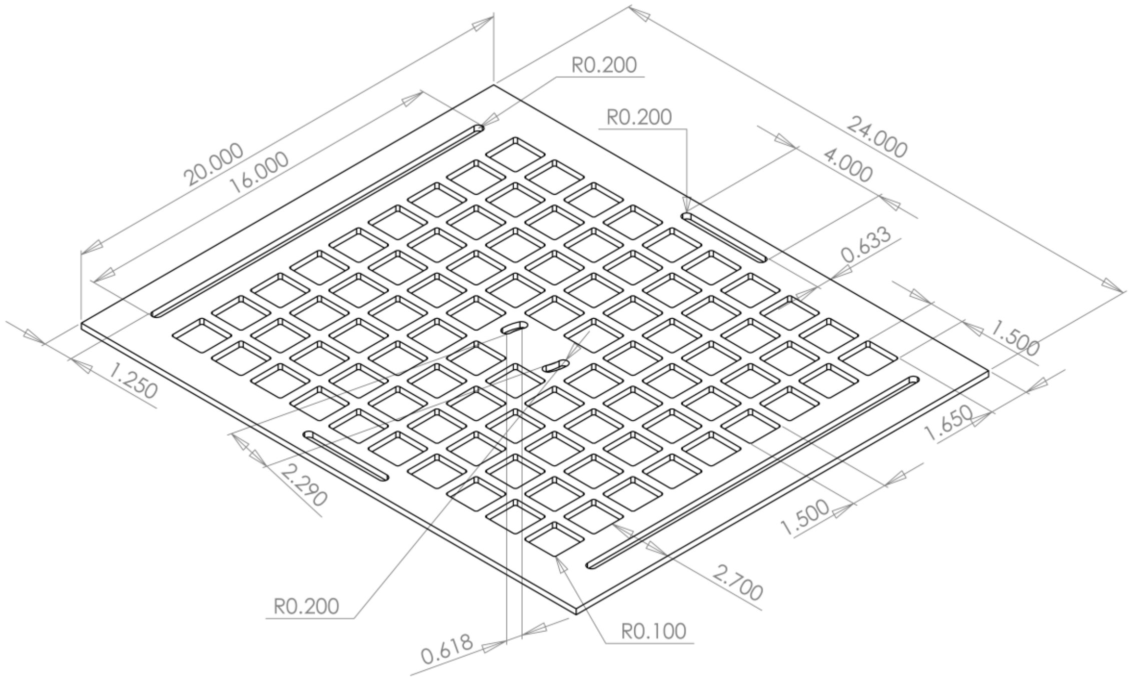

Figure 4 - Carburizing Fixture w/ Dimensions in Inches

After the samples were carburized, the wires attaching them to the fixture were carefully broken off. The loose samples were placed in plastic bags and sorted into a padded bin for transport back to the laboratory for analysis. They were then cut and smoothed at the cross sections and technical data was collected.

5.0 Results

5.1 Samples

The samples remained easily identified and undamaged throughout the experiment.

5.2 Cleaning Fixture

The cleaning fixture worked as intended. The samples were attached, cleaned, removed, and stored without damage. Although unwieldy, for only two cleaning cycles, the system and procedure was functional

5.3 Carburizing Fixture

The brackets had sufficient clearance to fit around the variable widths of rods that made up the crates. The brackets and hardware used to connect them held during the carburizing. The carburizing fixture grid allowed for enough cross sections to attach all the required testing samples with enough spacing between them such that they did not interfere with each other. The carburizing fixture did distort a considerable amount due to creep (Figure 5), however it did not fail. The center bracket proved essential considering the amount of creep that the carburizing fixture sustained.

The data collected was useful and the experiment a success.

Figure 5 - Fixture After Creep

6.0 Recommendations

For multiple repetitions of this experiment development of more permanent fixtures would be advantageous. The hardening process in the experiment creates an extremely brittle carburizing fixture, making it unsuitable for reuse. As this experiment was not repeated, primary concerns were ease of manufacturing and materials cost. Future fixtures should be designed for ease of use and made of materials that are better able to withstand the harsh conditions of carburization. Also, the cleaning fixture could be set up in such a way that the all of the samples could be easily placed into it, secured for the cleaning process, and then easily removed.

The identification of samples could be improved. Rather than etching an identification code into each individual sample, the placement of each sample on the grid could be recorded. Once they are removed from the carburizing fixture the samples could be identified by nondestructive labels or be placed in labeled containers. This is to remove the possible effects of stress and surface area that etching the samples could cause.

The entire process could be simplified by setting a distinct timeline and having all the materials and testing equipment ready for implementation. This could significantly cut down the overall time to complete the experiment. Also, some processes could be combined or simplified to allow for increased efficiency. For example, rods of each material selected could have their faces roughed or smoothed in the CNC lathe before cutting each sample. This would generate samples with one side already processed according to design parameters and would be relatively easy to program.

One possibility for future work would be to use a larger cleaning system, which could hold all samples simultaneously. The fixture for this system could be designed for uses in for both cleaning and carburization processes. This would eliminate more steps, reducing opportunities for samples to have their integrity compromised. Again, if scheduling was more efficient there would be less time that samples would be exposed to the air and the possibility of contamination. For example the carburizing process could be scheduled immediately after cleaning was completed.

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