EFFECTS OF CARBURIZATION PROCESS ON THE MECHANICAL PROPERTIES OF CARBURIZED MILD STEEL

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Report submitted fulfillment of the requirements for the award of the degree of Bachelor of Engineering in Manufacturing

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JUNE 2013
ABSTRACT

Due to the complexity of parameters in carburizing, there has been relatively little work on process variables during the surface hardening process. This work focuses on the effects of carburization process on the mechanical properties of carburized mild steel, at constant temperature, 850°C with different time, 2 hours, 4 hours and 6 hours and quenched in oil. The objectives of this project are to study the influence of carburization process for mild steel and to study the material performance after carburization process. After carburization process, the test samples were subjected to standard test and form the data obtained, ultimate tensile strength and Young’s modulus were calculated. The case hardness of the carburized samples were measure. It was observed that the mechanical properties of mild steels were found to be strongly influenced by the process of carburization. It was conclude that the sample carburized at 850°C soaked for four hours followed by oil quenching were better because they showed the higher ultimate tensile strength at 541.41096 MPa.
ABSTRAK

Disebabkan kerumitan parameter dalam pengkarbonan, terdapat sedikit perubahan terhadap pembolehubah proses semasa proses pengerasan permukaan. Kerja ini memberi tumpuan kepada kesan proses pengkarbonan pada sifat-sifat mekanikal keluli lembut, pada suhu malar, 850°C dengan masa yang berbeza, dua jam, empat jam dan enam jam dan direndam dalam minyak. Objektif projek ini adalah untuk mengkaji pengaruh proses pengkarbonan terhadap keluli lembut dan mengkaji prestasi bahan selepas proses pengkarbonan. Selepas proses pengkarbonan, sampel ujian telah dikenakan ujian standard dan data diperolehi seperti kekuatan tegangan muktamad dan modulus Young. Kesimpulan yang boleh dibuat adalah sampel pengkarbonan pada suhu 850°C dan direndam selama empat jam diikuti oleh pelindapkejutan minyak adalah lebih baik kerana ia menunjukkan kekuatan tegangan muktamad yang lebih tinggi iaitu 541,41096 MPa.
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<tr>
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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

This project is to study the effects of carburization time and temperature on the mechanical properties of carburized mild steel, using activated carbon as carburizer. Carburizing is a process where the steel is heated in a furnace. By means of a carbonaceous medium (gas or salts) the outside layer of a carbon poor component is enriched with carbon by means of carbon diffusion. The increase of carbon content causes the material to harden. The result is a hard and wear resistant surface with a tough core. The carburizing process does not harden the steel it only increases the carbon content to some pre determined depth below the surface to a sufficient level to allow subsequent quench hardening.

As we know there is a little bit of steel in everybody life. Steel has many practical applications in every aspects of life. Steel with favorable properties are the best among the goods. The steel is being divided as low carbon steel, high carbon steel, medium carbon steel, high carbon steel on the basis of carbon content.

Low carbon steel has carbon content of 0.15% to 0.45%. Low carbon steel is the most common form of steel as it’s provides material properties that are acceptable for many applications. It is neither externally brittle nor ductile due to its lower carbon content. It has lower tensile strength and malleable. Steel with low carbon steel has properties similar to iron. As the carbon content increases, the metal becomes harder and stronger but less ductile and more difficult to weld.

Carburizing as a diffusion controlled process, so the longer the steel is held in the carbon-rich environment, the greater the carbon penetration will be and the higher the carbon content. The carburized section will have carbon content high enough so that it
can be hardened again through flame or induction hardening. Surface hardening processes are influenced by heat treatment temperature, rate of heating and cooling, heat treatment period, quenching media and temperature as investigated by Schimizu and Tamura [6]. Post heat treatment and pre-heat treatment processes are the major influential parameters, which affect the quality of the part surface hardened. Hardenability is essentially the ease of forming martensite and reflects the ability of a steel to be hardened to a specified depth.

The carburizing furnaces are either gas fired or electrically heated. The carburizing temperature varies from 870 to 940 °C the gas atmosphere for carburizing is produced from liquid or gaseous hydrocarbons such as propane, butane or methane. The study of process parameters in metals during heat treatment has been of considerable interest for some years[4,5,6,7] but there has been relatively little work on process variables during the surface hardening process[8] since controlling parameters in carburization is a complex problem. The major influencing parameters in carburization are the holding time, carburizing temperature, carbon potential and the quench time in oil. The present work is focused on the effects of carburizing temperature and holding time on the mechanical properties of carburized mild steel.

1.2 PROBLEM STATEMENT

Now days, we can see the demand on making a suitable metal for some condition. For example they will be used in automotive or construction where they required a metal that can stand with certain condition at the low cost of manufacturing process. In order to meet such condition satisfactorily, a material of a soft and tough nature should be employed - something that possesses strength and resistance to wear, and still conforms to standard practice of design regarding the proportions of parts. Such problems have come and have to be met by the manufacturer; they constitute the problem of casehardening. It is not a new subject it is not well understood and not always easy to control.

In this project, we can simulate the suitable casehardening process by control only the time of carbonizing process itself. As we know too much steel absorbs carbon at
certain rates depending on the temperature and time will affect the carbon penetration. If an excess of carbon is liberated, the surface of the steel becomes supersaturated with carbon, the result being a brittle structure.

The result that we get from this experiment will be compare to get the optimum time with the greater hardness can achieve without changing the specimen to brittle material. These will help manufacture to estimate the optimum time for carbonizing process can be done in order to get high quality material at the minimum/optimum cost.

1.3 OBJECTIVES

The objectives of the project are:

- To study the influence of carburization process for mild steel.
- To study the material performance after carburization process.

1.4 PROJECT SCOPE

The scopes of this project are:

- Carburization process has been carried out with constant temperature, 850°C with different time, two hours, four hours and six hours.
- Material performance measuring using Optical Microscope, Vickers Hardness Test and Tensile equipment testing.
CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A review of the literature review was performed to identify studies relevant to the carburizing process, mild steel, and mechanical properties of carburized mild steel. A review of others relevant research also provided in this chapter. The review is detailed so that the information and older research can be used to improve this topic.

2.2 CARBURIZING PROCESS

Carburizing is a case-hardening process in which carbon is dissolved in the surface layers of a low-carbon steel part at a temperature sufficient to render the steel austenitic, followed by quenching and tempering to form a martensitic microstructure. The resulting gradient in carbon content below the surface of the part causes a gradient in hardness, producing a strong, wear-resistant surface layer on a material, usually low-carbon steel, which is readily fabricated into parts. (J.R Davis, 1998)

In gas carburizing, commercially the most important variant of carburizing, the source of carbon is a carbon-rich furnace atmosphere produced either from gaseous hydrocarbons, for example, methane (CH₄), propane (C₃H₈), and butane (C₄H₁₀), or from vaporized hydrocarbon liquids. (J.R Davis, 1998)
Low-carbon steel parts exposed to carbon-rich atmospheres derived from a wide variety of sources will carburize at temperatures of 850°C (1560°F) and above. In the most primitive form of this process, the carbon source is so rich that the solubility limit of carbon in austenite is reached at the surface of the steel and some carbides may form at the surface. Such atmospheres will also deposit soot on surfaces within the furnace, including the parts. While this mode of carburizing is still practiced in parts of the world in which resources are limited, the goal of current practice in modern manufacturing plants is to control the carbon content of furnace atmospheres so that:

- The final carbon concentration at the surface of the parts is below the solubility limit in austenite.
- Sooting of the furnace atmosphere is minimized.

Endothermic gas (Endogas) is a blend of carbon monoxide, hydrogen, and nitrogen (with smaller amounts of carbon dioxide, water vapor, and methane) produced by reacting a hydrocarbon gas such as natural gas (primarily methane), propane or butane with air. For endogas produced from pure methane, the air-to-methane ratio is about 2.5; for endogas produced from pure propane, the air-to-propane ratio is about 7.5. These ratios will change depending on the composition of the hydrocarbon feed gases and the water vapor content of the ambient air. (J. R Devis, 2002)

A carrier gas similar in composition to endogas produced from methane can be formed from a nitrogen-methanol blend. The proportions of nitrogen and methanol (CH₃OH) are usually chosen to give the same nitrogen-to-oxygen ratio as that of air, that is, about 1.9 volumes of nitrogen for each volume of gaseous methanol.

The successful operation of the gas carburizing process depends on the control of three principal variables:
- Temperature
- Time
- Atmosphere composition.

Other variables that affect the amount of carbon transferred to parts include the degree of atmosphere circulation and the alloy content of the parts.
The maximum rate at which carbon can be added to steel is limited by the rate of diffusion of carbon in austenite. This diffusion rate increases greatly with increasing temperature; the rate of carbon addition at 925°C (1700°F) is about 40% greater than at 870°C (1600°F). (J. R Devis, 2002)

The temperature most commonly used for carburizing is 925°C (1700°F). This temperature permits a reasonably rapid carburizing rate without excessively rapid deterioration of furnace equipment, particularly the alloy trays and fixtures. The carburizing temperature is sometimes raised to 955°C (1750°F) or 980°C (1800°F) to shorten the time of carburizing for parts requiring deep cases. Conversely, shallow case carburizing is frequently done at lower temperatures because case depth can be controlled more accurately with the slower rate of carburizing obtained at lower temperatures. (J. R Devis, 2002)

Therefore, for best results, the workload should be heated to the carburizing temperature in a near-neutral furnace atmosphere. In batch furnaces, parts can be heated in Endogas until they reach the furnace temperature; then carburizing can commence with the addition of the enriching gas. Many new continuous furnaces are being built with separate preheat chambers to ensure that the load is at a uniform temperature before entering the carburizing zone. In continuous furnaces that lack positive separation between heating and carburizing stages, the best that can be done is to:

- Add only Endogas to the front of the furnace.
- Establish a front-to-back internal flow of atmosphere gases by adjusting flow rates and orifice size in the effluent lines at either end of the furnace.

The effect of time and temperature on total case depth shows that the carburizing time decreases with increasing carburizing temperature. In addition to the time at the carburizing temperature, several hours may be required to bring large work pieces or heavy loads of smaller parts to operating temperature. For a work piece quenched directly from the carburizing furnace, the cycle may be lengthened further by allowing time for the work piece to cool from the carburizing temperature to about 843°C prior to quenching. Similarly, additional diffusion and interchange of carbon with the atmosphere will occur during cooling prior to quenching. More complex mathematical models that allow for variations in temperature and atmosphere carbon potential with time can be constructed to allow a better prediction of case depth. (J. R Devis, 2002)
The carbon potential a furnace atmosphere at a specified temperature is defined as the carbon content pure iron that is in thermodynamic equilibrium with the atmosphere. The carbon potential of the furnace atmosphere must greater than the carbon potential of the surface of the work pieces in order for carburizing to occur. It is the difference in carbon potential that provides the driving force for carbon transfer to the parts.

The combined effects of time, temperature, and carbon concentration on the diffusion of carbon in austenite can be expressed by Fick’s laws of diffusion.

Fick’s first law states that the flux of the diffusing substance perpendicular to plane of unit cross-sectional area is proportional to the local carbon gradient perpendicular to the plane. The constant of proportionality is the diffusion coefficient \( D \), which has the units (distance)\(^2\)/time. Fick’s second law is a material balance within elemental volume of the system; the flux carbon into an elemental volume of iron minus the flux of carbon out of the elemental volume equals the rate of accumulation of carbon within the volume. Combining the two laws leads to a partial differential equation that describes the diffusion process. (J. R Devis, 2002)

2.3 MILD STEEL

Mild steel is a type of steel that contains only a small amount of carbon and other elements. It is softer and can be shaped more easily than higher carbon steels. It also bends a long way instead of breaking because it is ductile. It is used in nails and some types of wire, it can be used to make bottle openers, chairs, staplers, staples, railings and most common metal products. Its name comes from the fact it only has less carbon than steel.

Mild steel, also called plain-carbon steel, is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications, more so than iron. Low carbon steel contains approximately 0.05–0.3% carbon and mild steel contains 0.3–0.6% carbon; making it malleable and ductile. Mild steel has a relatively low tensile strength, but it is cheap.
and malleable; surface hardness can be increased through carburizing. (http://en.wikipedia.org/wiki/Carbon)

It is often used when large quantities of steel are needed, for example as structural steel. The density of mild steel is approximately 7.85 g/cm³ (7850 kg/m³ or 0.284 lb/in³) and the Young’s modulus is 210 GPa (30,000,000 psi).

Low carbon steels suffer from *yield-point runout* where the material has two yield points. The first yield point (or upper yield point) is higher than the second and the yield drops dramatically after the upper yield point. If a low carbon steel is only stressed to some point between the upper and lower yield point then the surface may develop Lüder bands. Low carbon steels contain less carbon than other steels and are easier to cold-form, making them easier to handle. (http://en.wikipedia.org/wiki/Carbon_steel)

2.4 QUENCHING

In materials science, quenching is the rapid cooling of a workpiece to obtain certain material properties. It prevents low-temperature processes, such as phase transformations, from occurring by only providing a narrow window of time in which the reaction is both thermodynamically favorable and kinetically accessible. For instance, it can reduce crystallinity and thereby increase toughness of both alloys and plastics (produced through polymerization). (http://www.astarmathsandphysics.com/a_level_physics_notes/materials/a_level_physics_notes_quenching.html)
In metallurgy, it is most commonly used to harden steel by introducing martensite, in which case the steel must be rapidly cooled through its eutectoid point, the temperature at which austenite becomes unstable. In steel alloyed with metals such as nickel and manganese, the eutectoid temperature becomes much lower, but the kinetic barriers to phase transformation remain the same. This allows quenching to start at a lower temperature, making the process much easier. High speed steel also has added tungsten, which serves to raise kinetic barriers and give the illusion that the material has been cooled more rapidly than it really has. Even cooling such alloys slowly in air has most of the desired effects of quenching.

Extremely rapid cooling can prevent the formation of all crystal structure, resulting in amorphous metal or "metallic glass". (http://en.wikipedia.org/wiki/Quenching)

When quenching, there are numerous types of media. Some of the more common include: air, nitrogen, argon, helium, brine (salt water), oil and water. These media are used to increase the severity of the quench. (Todd, Robert H., Dell K. Allen, and Leo Alting, 2009)
2.5 TENSION

The tension test is the most common test for determining such mechanical properties of materials as strength, ductility, toughness, elastic modulus and strain hardening capability. The test first requires the preparation of a test specimen, typically shown in Figure 2.1. In the United State, the specimen is prepared according to ASTM specifications. Otherwise, it is prepared to the specifications of the appropriate corresponding organization in other countries. Although most tension-test specimens are solid and round, they also can be flat or tubular. (S. Kalpakjian and S. R. Schmid, 2006)

Figure 2.1: Shape of ductile specimen at various stages of testing
2.5.1 Tensile Specimen

A tensile specimen is a standardized sample cross-section. It has two shoulders and a gauge (section) in between. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in this area.

The shoulders of the test specimen can be manufactured in various ways to mate to various grips in the testing machine. Each system has advantages and disadvantages; for example, shoulders designed for serrated grips are easy and cheap to manufacture, but the alignment of the specimen is dependent on the skill of the technician. On the other hand, a pinned grip assures good alignment. Threaded shoulders and grips also assure good alignment, but the technician must know to thread each shoulder into the grip at least one diameter's length, otherwise the threads can strip before the specimen fractures. ([http://en.wikipedia.org/wiki/Tensile_testing](http://en.wikipedia.org/wiki/Tensile_testing))

In large castings and forgings it is common to add extra material, which is designed to be removed from the casting so that test specimens can be made from it. These specimens may not be exact representation of the whole workpiece because the grain structure may be different throughout. In smaller workpieces or when critical parts of the casting must be tested, a workpiece may be sacrificed to make the test specimens. For workpieces that are machined from bar stock, the test specimen can be made from the same piece as the bar stock. ([http://en.wikipedia.org/wiki/Tensile_testing](http://en.wikipedia.org/wiki/Tensile_testing))
2.6 VICKERS HARDNESS TEST

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting.

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation. (http://www.indentec.com/downloads/info_vickers_test.pdf)

![Vickers indentation and measurement of impression diagonals](http://www.indentec.com/downloads/info_vickers_test.pdf)

**Figure 2.2:** Vickers indentation and measurement of impression diagonals


F= Load in kgf

d = Arithmetic mean of the two diagonals, d1 and d2 in mm
Table 2.1: Standard Vickers scale

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<th>Low-force hardness scales</th>
<th>Test force F (N)</th>
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<td>HV 0.2</td>
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<td>29.42</td>
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3.1 INTRODUCTION

In this chapter, the methodology of this study was carefully discussed in details. The specimen type for this study is Mild Steel. Methodology included in this study is dividing into several steps which are sample preparation, carburizing process, mechanical properties test and analysis on carburized specimens by using Optical Microscope, Vickers Hardness test and tensile testing equipment.

3.2 METHODOLOGY FLOW CHART

Methodology flow chart is use as guidelines and the sequences to make this project go with a smooth. As illustrated in Figure 3.1, firstly literature review was been study with the field that regards to this project. Then, the process begins with preparing the sample of specimens, Mild Steel. In this experiment, the constant temperature, 850°C with different time will be used in carburizing process.
Figure 3.1: Flow chart of project