

Surface properties and activation energy analysis for superplastic carburizing of duplex stainless steel

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Abstract

A new surface carburizing technique which combines superplastic phenomenon and carburizing process called superplastic carburizing (SPC) was introduced and compared with conventional carburizing (CC) process. Both processes were conducted on duplex stainless steel (DSS), which has been thermo-mechanically treated to obtain fine grain microstructure and exhibit superplasticity. Both processes were carried out at temperatures ranging from 1123 to 1223 K for various durations. Metallographic studies revealed a uniform, dense and smooth morphology of carbon layer was formed on all carburized specimens. For CC process, the thickness of carbon layer were in the range of 15–65 μm , while a much higher carbon layer thickness in the range of 17–75 μm was formed on the surface of carburized DSS through SPC process. Surface hardness values of carburized specimens through CC process were between 682 and 1300 HV, while through SPC process the surface hardness was increased significantly between 737 and 1648 HV. Activation energy for SPC was determined as 151.87 kJ/mol, which is lower compare to 198.58 kJ/mol for CC process. The results indicate that SPC process accelerates the diffusion of carbon atoms into the surface of DSS, thus increasing the thickness of carburized layer as well as the surface hardness and lower activation energy.

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1. Introduction

Nowadays, structural materials require various properties such as high strength, excellent corrosion and wear resistant due to the demands for high performance and severe service environments of machine components. In order to meet these demands, it is believed that application of several surface engineering techniques would be able to improve and enhance the properties of the materials used. Carburizing process is one of the most popular methods to harden the surface and enhance the properties of steel. It has been practiced for many years to increase the surface hardness and wear resistance of the components made from steel. Carburizing is usually done at elevated temperatures with a carbon medium such as solid, liquid or gas. These mediums could supply adequate quantity of atomic carbon for absorption and diffusion into the steel [1,2].

Meanwhile, the ability of certain materials to exhibit large degree of elongations prior to failure known as superplasticity has been recognized for about seven decades [3]. Superplasticity can also be defined as a phenomenon of metals that can show a very large plastic deformation at high temperature. Superplastic materials are characterized by the fine and stable grain structure with grain sizes less than 10 μm with a constant forming temperature of around half the absolute melting point. The high ductility achieved through superplastic materials is exploited to form components with complex shapes. It is now being utilized commercially where the scope of applications has extended beyond the aerospace industry that includes the fabrication of many components in the automotive industry [3]. Furthermore, superplasticity or superplastic deformation in metals has been found to be beneficial in manufacturing devices and parts for industrial applications.

On the other hand, DSS are characterized by their balanced ferrite/austenite microstructures and very well known for their superior corrosion resistance and high strength compared to other stainless steels [4]. Due to their superior properties, DSS are widely utilized in the oil and gas production

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Table 1
Chemical composition of duplex stainless steel (JIS SUS329J1) (wt%)

C	0.06
Si	0.42
Mn	0.30
P	0.03
S	0.06
Ni	4.18
Cr	24.5
Mo	0.49
Fe	Balance

and transmission, petroleum industries, petrochemical process plants, shipbuilding, transportation and for pulp and paper production equipments [5,6]. In the last 30 years, DSS also has been studied and characterized as one of the superplastic materials [7].

The aim of this study is to investigate the prospect of combining carburizing process with superplastic phenomenon in order to obtain a more efficient process and better properties of carburized specimen. DSS with fine grain size that able to exhibit superplasticity at high temperature has been choose as substrate material in this study [8].

2. Experimental procedure

2.1. Substrate material

Duplex stainless steel (JIS SUS329J1) was used as substrate material. The chemical composition of the material is presented in Table 1. In order to obtain a fine grain microstructure and superplastic characteristic, the as-received DSS was initially solution-treated at 1573 K for 1 h and followed by water quenching. The solution treated DSS was then subjected to cold-rolling with a reduction area of 75%. The specimens for both carburizing processes were cut from the thermo-mechanically treated plate to a dimension of 10 mm × 10 mm × 8 mm.

2.2. Carburizing processes

Prior to carburizing process, specimen surfaces were polished using emery paper and cleaned by alcohol to remove oxide layers and irregularities in order to enhance carbon uniformity [4]. Fig. 1 shows the stainless steel container used in the conven-

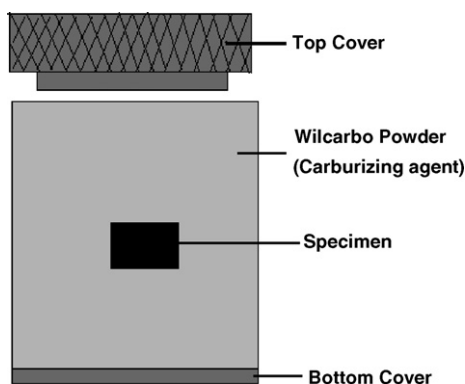


Fig. 1. Schematic diagram of conventional carburizing container.

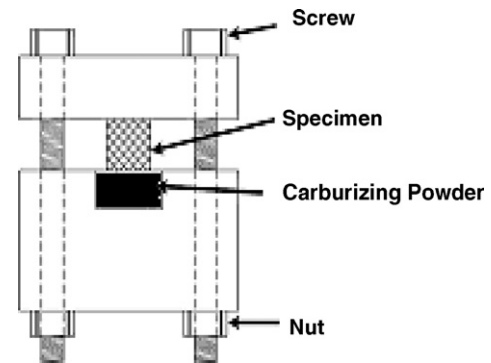


Fig. 2. Schematic diagram of superplastic carburizing clamp.

tional carburizing (CC) process. The specimen was packed in the middle of the stainless steel container filled with Wilcarbo powder (carburizing agent). The container was tapped until the powder densely packed to prevent air trap within the powders. This assembly was then heated in a furnace with controlled atmospheric condition for 2–8 h at temperatures from 1123 to 1223 K. The carburized specimen was then air-cooled to room temperature.

Meanwhile, the superplastic carburizing (SPC) process was conducted using a specially designed clamp fabricated from stainless steel. The schematic set up of the clamp for SPC process is shown in Fig. 2. This clamp is consists of upper block, lower block with a hole in the middle and two screws attached with nuts. Wilcarbo powder (carburizing agent) was filled inside the middle hole of the lower block. The specimen was mounted on top of the densely packed Wilcarbo powder and an initial pressure of about 74 MPa was applied by tightening the screws and nuts together using a torque wrench. This assembly was then heated in a furnace with similar conditions as the earlier CC process. Fig. 3 shows the process diagram for both carburizing processes.

2.3. Carbon layer thickness and microstructure characterization

The cross-section of carburized specimen was ground with emery paper up to 1200 grit and polished until a mirror like surface was obtained. The microstructure of carburized DSS was then revealed by using a special etchant containing hydrochloric acid (HCl) saturated with ferric chloride (FeCl_3).

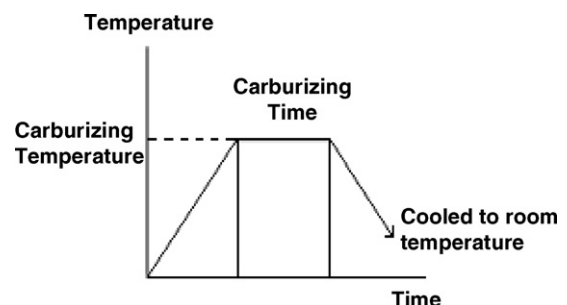


Fig. 3. Process diagram of conventional carburizing and superplastic carburizing process.

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