Team 18F2 KineticA

Surface Treatment Analysis

Carburizing, Shot Peening, and Tempering Analysis

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1 Introduction

Contained within this report is an analysis and display of findings for three different surface treatments. These surface treatments (tempering, carburizing, and shot peening) are not usually used on aluminum mechanisms but rather steel. Thus, the need for an analysis and research has been found so the group can determine the best and most realistic surface treatments to do on their gearsets. Discussion of the treatments follow in section 2.

2 Surface Treatments

Contained within this section of the report is a description and discussion on each surface treatment being analyzed in this report. Below, carburizing, shot peening, and tempering are detailed.

2.1 Carburizing

The process of carburizing involves coating the surface in a material containing a high carbon content. This material is, many times, a sort of charcoal or coal. Then, high levels of heat are applied for extended periods of time drastically increasing the rate of diffusion. For our project, the group looks to carburize aluminum and so, the process would create a thin layer of aluminum carbide on the surface which will be stronger than an aluminum surface.

2.2 Shot Peening

The surface treatment process of shot peening involves shooting small metallic (or ceramic) pellets at the surface of the component. By shooting these pellets, small dimples are made in the material which creates regions of high tension and compression which strengthens the material. An image to visualize the process is shown below (Figure 2.2)

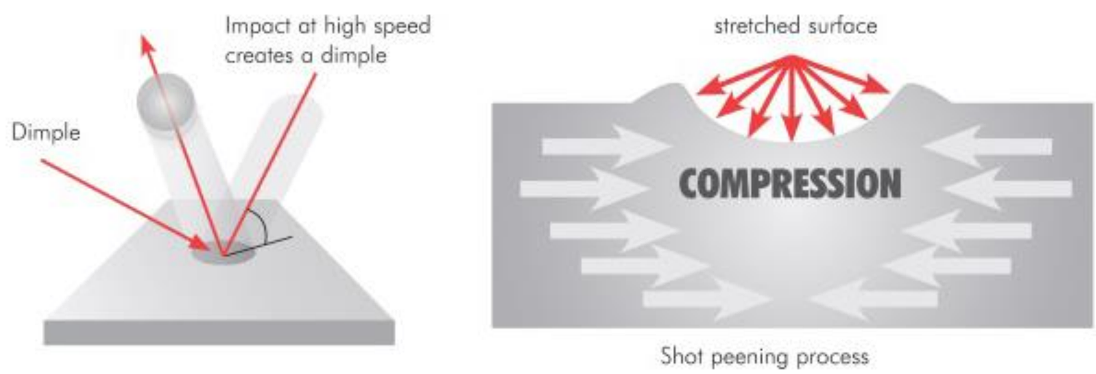

FIGURE 2.2 SHOT PEENING VISUALIZATION

By completing the shot peening process, the surface becomes much rougher and allows the material to strengthen due to compression.

2.3 Tempering

The process of tempering involves heating and cooling the component to its lower critical temperature in order to increase the hardness of the material. Once the material is brought up to its lower critical temperature, it's held at a constant state for a specific period of time. The material is then cooled by either quenching or allowed to cool naturally. This process works similarly to annealing but increases the brittleness of the material rather than the ductility.

3 Equations

Contained within this section of the report are the equations that have been found for each of the surface treatments to determine the proper times, heats, diameters, etc. needed.

3.1 Carburizing

In order to find the time for carburizing, the desired depth must be determined by the group. Once this depth has been found, the equation is simple in order to find the heating time in hours. The equation is below in equation 1.

$$Heating\ Time = \left(\frac{Desired\ Depth\ mm}{.2}\right) + 3 \tag{1}$$

3.2 Shot Peening

In order to determine how rough to make the surface for shot peening and how much the effect will be, one must first determine the dent diameter desired. The equation to find the dent diameter is below (equation 2).

$$C = a_1(MV^2)^{\frac{1}{3}}HVW^{-\frac{1}{3}} + a_2\left(\frac{M}{HVW}\right)^{\frac{1}{2}} + a_3\left(\frac{3M}{\frac{4\pi}{\rho}}\right)^{\frac{1}{3}} + a_4 \tag{2}$$

Where a_1 = 0.074, a_2 = 726.728, a_3 = 0.049, a_4 = 0.011, C = dent diameter (mm), M = mass (g), V = speed (mm/s), HVW = Vickers hardness, and ρ = density (g/mm^3).'

By determining the dent diameter and maximum surface roughness, the team is able to determine the exact change of the material due to shot peening. The equation to find the maximum surface roughness is below (equation 3).

$$R = a_1(MV^2)^{\frac{1}{3}}HVW^{-\frac{1}{3}} + a_2\left(\frac{M}{HVW}\right)^{\frac{1}{2}} + a_3\left(\frac{3M}{\frac{4\pi}{\rho}}\right)^{\frac{1}{3}} + a_4 \tag{3}$$

Where a_1 = 0.020, a_2 = 2602.19, a_3 = 0.726, a_4 = 0.104. The other variables are constant with those in equation 2.

3.3 Tempering

For tempering, the equation used (below) is referred to as the Hollomon-Jaffe parameter. The value is also known as the tempering parameter.

$$H_p = \frac{T}{1000}(C + \log(t)) \tag{4}$$

Where T = temperature (k), C = Holomon-Jaffe constant, and t = time (s).

The material parameter "C" is an experimental value that was found by plotting hardness vs. tempering time and interpolating the data. However, it can be found algebraically through the use of equation 5 (below).

$$C = 21.3 - (5.8 * Wt\%\ Carbon) \tag{5}$$

By finding the Hollomon-Jaffe parameter, one can see the effectiveness of tempering at various temperatures and times for a given material. The higher the value, the better the effect.

4 Assumptions

In this section of the report, each assumption being used for each respective surface treatment is detailed below.

4.1 Carburizing

In order to properly determine the heating time of the aluminum for carburizing, the group has assumed the temperature of the treatment to be constant at 850˚C. By making this assumption, the general carburizing equation (1) simplifies down into the equation displayed in section 3.1 and allows for a simple calculation. For the calculation, the heating time will be determined for a desired depth between 0.1 mm and 3 mm.

4.2 Shot Peening

Within the shot peening equations, assumptions will be made in order to allow the calculations to be determined. By assuming the pellets to be cast steel shot with a mass of around 0.2 g and the speed of the pellets as 25 m/s, the group is then able to look into the Vickers hardness values and density values of aluminum. After research, the HVW value of aluminum is 107, and the density of aluminum is 2.7 g/mm^3.

4.3 Tempering

In order to determine the Hollomon-Jaffe parameter for tempering aluminum, three values must be assumed. First, the temperature range will be between 500-1000 K and the time will be between 30 minutes to 5 hours. Lastly, the percent weight of carbon in the aluminum alloy is assumed to be 1%.

5 Calculation Results and Impact/Conclusions

In this section of the report, the results of the calculations and their impacts are discussed.

5.1 Calculations

Below (sections 5.1.1 through 5.1.3) are the results of the calculations for the analysis of each surface treatment. These results will help the group to determine which surface treatments are worth doing to their aluminum components.

5.1.1 Carburizing

By plotting equation 1 for a range of depths from 0.1 mm to 3 mm, the results are shown below (Figure 5.1.1).

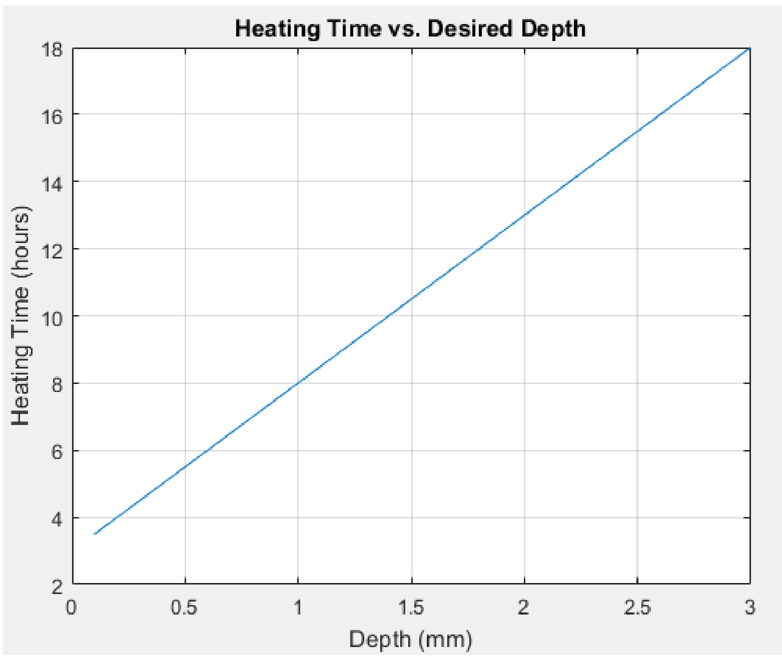

FIGURE 5.1.1 HEATING TIME VS. DESIRED DEPTH

Analyzing the results of the plot, the group can see a linear relationship between the heating time and treatment depth. As one can see, in order to have 3 mm of aluminum carbide from the surface treatment, it would require 18 hours of carburization at a constant temperature of 850˚C. However, to achieve minimal depth from carburizing, 0.5 mm can be achieved in around 5.5 hours.

From these results, the group can see that the time required to properly carburize is a significant factor in the treatment.

5.1.2 Shot Peening

From running the calculations for shot peening, it was found through the assumptions in section 4.2 that the dent diameter (C) = 0.8820 mm and the maximum surface roughness (R) would be 2.8437. These values allow the team to discuss the effect shot peening will have on the aluminum components of the project.

5.1.3 Tempering

Lastly, by applying and graphing equation 5 with a ranging time and temperature, the figures (below) have been found. The figure below (Figure 5.1.3a) shows a positive correlation between the Holomon-Jaffe constant and heating temperature. Thus, increasing the temperature will create a better effect and strengthen the material more.

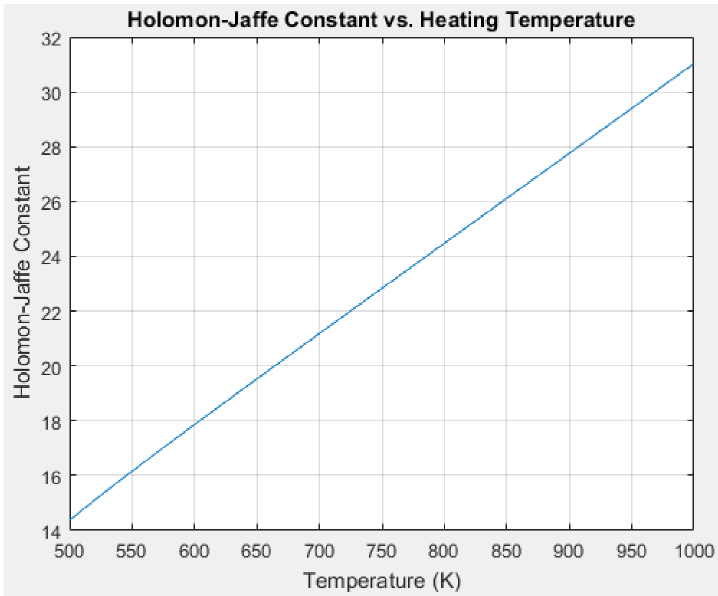

FIGURE 5.1.3A: HOLOMON-JAFFE CONSTANT VS. HEATING TEMPERATURE

The figure below (Figure 5.3.1b) shows how the tempering time effects the Holomon-Jaffe constant. This figure shows a positive correlation as well showing that increasing heating time increases the tempering effect.

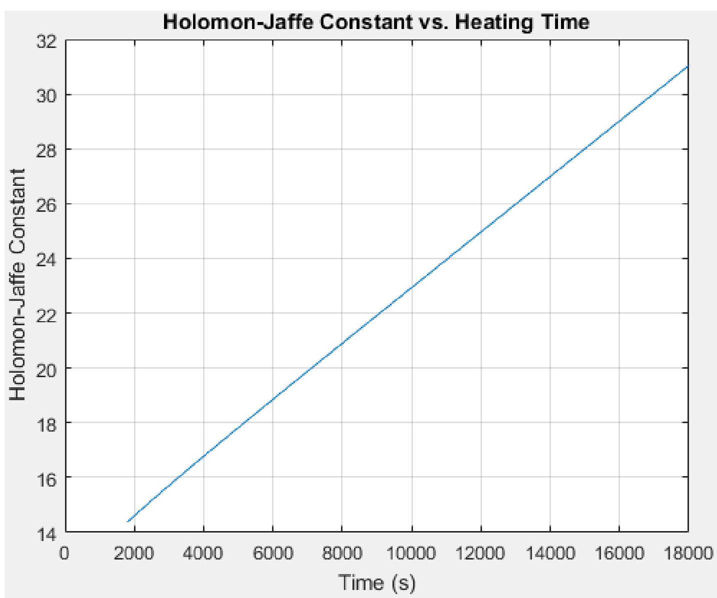

FIGURE 5.3.1B: HOLOMON-JAFFE CONSTANT VS. HEATING TIME

From the results of the tempering calculations, it can be seen that increasing the heating temperature and time will increase the Holomon-Jaffe constant and, thus, increase the effect of tempering.

5.2 Impact/Conclusions

In conclusion, by calculating the time(s), temperatures, and effects of the different surface treatments, the group has determined that carburizing would not be a good course of action for the group to take. This is because of the time and temperature required for a minimal effect. However, tempering could be an easier option for the group to do for the surface treatment of the aluminum components. It was determined that shot peening would be the easiest, most effective, hardening treatment to be done on the aluminum components for the project.

6 References

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7 MATLAB Code

```
clear
clc
close all
format short

%Carburizing
depth = .1:.01:3;                  %mm
HeatingTime = ((depth/.2)+3);      %hours

figure;
plot(depth,HeatingTime);
title('Heating Time vs. Desired Depth')
xlabel('Depth (mm)')
ylabel('Heating Time (hours)')
grid on

%Shot Peening
M = .2;                            %g
V = 25;                            %m/s
HVW = 107;
p = 2.7;                           %g/mm^3

a1 = .074;
a2 = 726.728;
a3 = .049;
a4 = .011;

C = a1*((M*V^2)^(1/2))*(HVW^(-
1/3))+a2*((M/HVW)^1/2)+a3*(((3*M)/((4*pi)/p))^(1/2))+a4 %mm

a1 = .02;
a2 = 2602.19;
a3 = .726;
a4 = .104;

R = a1*((M*V^2)^(1/2))*(HVW^(-
1/3))+a2*((M/HVW)^1/2)+a3*(((3*M)/((4*pi)/p))^(1/2))+a4 %mm

%Tempering
T = 500:1:1000;                    %K
t = 1800:32.4:18000;               %s
Percent = .01;

C = 21.3 - (5.8*Percent);

Hp = (T/1000).*(C+log(t));

figure;
plot(T,Hp);
title('Holomon-Jaffe Constant vs. Heating Temperature')
xlabel('Temperature (K)')
ylabel('Holomon-Jaffe Constant')
grid on
```

```
figure;
plot(t,Hp);
title('Holomon-Jaffe Constant vs. Heating Time')
xlabel('Time (s)')
ylabel('Holomon-Jaffe Constant')
grid on
```