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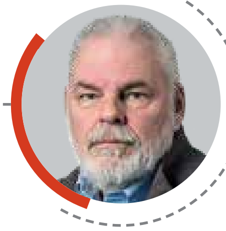

Determining carbon potential for neutral hardening or carburizing

Effect of steel alloying content on the effective atmosphere carbon potential.

To successfully heat-treat or carburize the many different alloys seen in the heat-treating shop, it is necessary to properly control the carbon potential of the atmosphere. In neutral hardening, this means that the carbon potential is neutral to the part and is neither carburizing nor decarburizing. In carburizing, this means that the desired surface carbon content is achieved so that the desired case depth is achieved.

A typical heat-treating atmosphere for steel is shown in Table 1. The CO_2 concentration will vary depending on the desired carbon potential. Regardless of the source of the atmosphere, it is important that the carbon monoxide, CO, content be maintained at 20 percent (23 percent in the case of propane). If the carbon monoxide percentage is not maintained at 20 percent, then the oxygen probe will not read the correct carbon potential. If propane is used, then the carbon analyzer must be adjusted to reflect the percentage of CO from propane. All the charts and graphs used to determine carbon potential from dewpoint are based on a carbon monoxide content of 20 percent.

An oxygen probe or carbon probe consists of platinum electrodes separated by an yttrium-doped zirconia tube. The probe is inserted into the furnace or generator. An air supply of approximately 0.5 CFH of air is supplied to the probe as a reference. The differential oxygen partial pressure between the furnace atmosphere and the reference atmosphere sets up a voltage across the probe. By measuring this small voltage (measured in millivolts), the carbon potential can be determined. Thus, the furnace atmosphere carbon potential can be controlled by air and natural gas additions by monitoring the voltage potential across the probe. In modern instruments, this is done internally using microprocessors. In many ways, it operates in a similar fashion to the O_2 sensor in a car for proper combustion.

The advantage of an oxygen probe is that it is accurate and fast. A direct read-out of the carbon potential of the atmosphere is common. The probe has a high temperature range suitable for high temperature carburizing. Little maintenance is required.

The primary disadvantage of the oxygen probe is that it assumes a fixed CO content (typically either 20 percent for natural gas or 23 percent for propane). If the CO content is not at this fixed value, then the readings obtained by the probe are erroneous. The oxygen probe is also a ceramic tube, and prone to thermal or mechanical shock. It must be routinely replaced at roughly yearly intervals, depending on the application. Heavy carburizing can shorten the life of the probe. However, the accuracy, ease of use and lack of maintenance, generally outweigh the disadvantages.

CONTROL OF CARBON POTENTIAL

While it has been previously established that it is critical for the atmosphere composition to consist of 20 percent CO for the carbon probe to be read accurately, this carbon content is not necessarily that seen by the part. In atmosphere control during heat treatment, there are different reactions that occur:

- Reactions in the gas phase.
- Diffusion in the gas phase.
- Reactions at the steel surface.
- Diffusion in the steel.

Gas Species	Formula	Natural Gas	Propane	Nitrogen-Methanol
Carbon Monoxide	CO	20%	23%	20%
Hydrogen	H_2	40%	31%	40%
Carbon Dioxide	CO_2	0.30%	0.30%	0.30%
Water Vapor	H_2O	< 0.1%	< 0.1%	< 0.1%
Methane	CH_4	< 0.1%	–	–
Propane	C_3H_8	–	< 0.1%	–
Nitrogen	N_2	40%	46%	40%

Table 1: Typical furnace atmosphere composition.

The kinetics of the reactions in the gas phase can be neglected because they are sufficiently fast compared to the kinetics of carbon diffusion in the steel, and if the atmosphere is stable. It has been shown [1] [2] that diffusion in the gas phase is not rate determining. A properly calibrated carbon probe will provide an accurate representation of the atmosphere carbon potential provided that the atmosphere is stable and near equilibrium (and at 20 percent CO).

The activity of carbon in steel, a_c, in dilute solutions, is [3]:

$$a_c = 1.07q\left[\frac{c}{100-19.5c}\right]exp\left[\frac{4798.6}{T}\right]$$

Where T is the temperature in degrees K and q is the adjustment in carbon activity due to alloying element additions. The adjustment in the carbon activity coefficient, q, is given by [3]:

$$\begin{aligned} q = 1 + [\%Si](0.15 + 0.033[\%Si]) + 0.365[\%Mn] - [\%Cr](0.13 - 0.00055[\%Cr]) \\ + [\%Ni](0.03 + 0.00365[\%Ni]) - [\%Mo](0.025 - 0.01[\%Mo]) \\ - [\%V](0.22 - 0.01[\%V]) \end{aligned}$$

This data has been compiled for multiple alloys (Table 2). The calculations have been shown so the reader can check his/her (and my) work.

For the most part, the effective carbon potential is higher than the carbon content in the steel. In some steels, the effective carbon potential is slightly lower than the carbon content. In these cases, it is best to use the carbon content in the alloy. These equations are powerful when trying to neutral harden alloys with very tight decarburization of carburization limits. They enable precise and repeatable carbon control.

SAE Steel	%C	%Si	%Mn	%Cr	%Ni	%Mo	%V	HT T (°C)	HT T (°K)	a_γ	q	ac
SAE 1045	0.45	0.25	0.75					845	1118	0.39	1.33	0.51
SAE 1150	0.50	0.25	0.85					850	1123	0.43	1.37	0.58
SAE 4140	0.40	0.25	0.85	0.95		0.20		870	1143	0.31	1.24	0.38
SAE 4340	0.40	0.25	0.70	0.80	1.85	0.25		845	1118	0.34	1.27	0.43
SAE 5160	0.60	0.25	0.86	0.80				845	1118	0.53	1.27	0.67
SAE 6150	0.50	0.25	0.80	0.95			0.15	857	1130	0.41	1.19	0.49
SAE 8675	0.75	0.25	0.80	0.50	0.55	0.35		845	1118	0.69	1.30	0.89

Table 2: Effect of alloying concentration on the effective activity of carbon.

CONCLUSIONS

In this short article, we described a method for determining the proper carbon potential to use with a given alloy to reduce the chance for decarburization or carburization when neutral hardening. It can also be used to obtain the necessary carbon potential when carburizing and selecting the proper surface carbon content.

Should you have any questions regarding this article, or suggestions for future articles, please contact the author.

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