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MATERION

TECHNICALTIDBITS

MATERION PERFORMANCE ALLOYS

"Could you be more specific," he asked heatedly.
– A brief discussion on the importance of specific heat.

- **Heat Capacity (C)**
- **Specific Heat (c)**
- **Molar Heat Capacity**
- **Volumetric Heat Capacity**
- **Thermal Mass**
- **Thermal Inertia**

SPECIFIC HEAT AND THERMAL MASS

When water passes through a sponge from a wet side to a dry side, some of the water will be absorbed by the sponge before additional water can pass through. Similarly, as heat is passing through a conductor, a portion of it is stored in the material itself (in the form of atomic vibrations). In other words, the material will "warm up" before passing the thermal energy on.

Heat capacity (C) describes how much thermal energy is absorbed by a material during heating or lost during cooling. More precisely, it describes the amount of thermal energy stored in or released from the atomic vibrations of the material as it is heated or cooled, respectively. If you consider a heat transfer problem to be a thermal circuit, then heat capacity is the thermal equivalent of capacitance in electrical circuits or viscous damping in mass-spring-damper mechanical systems.

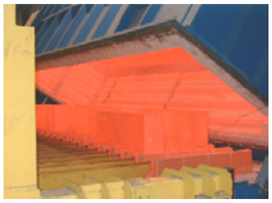
If a solid object absorbs a given amount of heat (Q) and its temperature rises by an amount (ΔT), then its heat capacity (C) is the ratio of the heat absorbed or lost to the change in temperature: $C = \frac{Q}{\Delta T}$. So, the units of heat capacity are J/K or BTU/˚F.

The material property **specific heat (c)** is the heat capacity per unit mass of the material. In a proper definition, specific heat measures how much energy it takes to change the temperature of a given mass of material by a given number of degrees. In SI units it is measured in J/kg K (how much energy must be absorbed to raise the temperature of 1 kg of material by 1 degree K), and in imperial units it is measured in BTU/lb ˚F. Please note that heat capacity is denoted with a capital "C", and specific heat is denoted by a lower case "c". Therefore in a monolithic (made from a single material) object of mass (m): $C = cm$.

Specific heat is not a constant, but like other thermal, electrical, and mechanical properties is a function of temperature. As the temperature rises, the specific heat increases. This means that progressively more thermal energy is stored with each degree of temperature rise as the overall temperature increases. (Technically speaking, specific heat is also a function of pressure, but the effect is generally not significant in solids and liquids.)

You may recall that in gasses, there are two general forms of specific heat. Namely, **specific heat at constant volume (c_v)** and **specific heat at constant pressure (c_p).** In each case, the pressure or volume of the gas is held constant as it is heated, and the other is allowed to change. In solid materials, both are assumed to be the same, but the specific heat of a solid is technically at constant pressure.

Molar heat capacity is a similar concept to specific heat, except that it is expressed as heat capacity per total amount of material in moles.



Volumetric heat capacity and **thermal mass** are other terms for heat capacity. By definition it is specific heat times mass, and it determines how much energy the material needs to absorb before it rises to a given temperature. The larger the thermal mass, the longer it will take for a material to come to temperature.

Thermal mass is why refrigerators and freezers are more efficient when fully stocked than when empty. When the door is opened, the cold air inside will rapidly be warmed and/or exchange with the warmer air outside. Due to its thermal mass, the cold food inside does not warm up as much as the air does when the door is opened. Therefore, only the air needs to be cooled once the door is closed again.

The next issue of Technical Tidbits will discuss thermal diffusivity and effusivity.

OTHER THERMAL PROPERTIES (CONTINUED)

If you are heat treating a large number of small parts at once, by piling them on a tray in the furnace, only those on the outside of the pile will heat up the fastest due to convective heat transfer. Those on the inside of the pile will take longer to reach temperature, since the heat must be conducted through the parts on the outside to reach them. All the parts in a heat treat furnace will come up to temperature more quickly when the overall thermal mass is low. Therefore, there is a trade-off between the amount of parts you can put in a furnace and the time it takes to provide a proper heat treatment.

Thermal inertia refers to the tendency for temperature changes to lag behind the driving heating and cooling forces. This can best be seen in weather patterns. In the summer, the amount of solar radiation received per day falls after the summer solstice in June, but the hottest weather comes in August. Similarly, the coldest weather of the year lags the winter solstice by about two months, even though the amount of solar radiation received each day has been steadily increasing. Even on a daily basis, the hottest part of the day is not when the sun is directly overhead (peak solar intensity), but is usually between one and three hours after. The thermal mass of the ground, oceans, large lakes, and water vapor in the air are the reasons why these lags occur.

Furthermore, if you watch cooking shows on television, you will know the importance of pulling roasted meats out of the oven to let them "rest" before serving. Even though the outer part of the meat is now being cooled instead of heated, the interior of the meet is still being cooked. If you were to slice the meat before resting, the interior will be undercooked. On the other hand, if you leave the meat in the oven until the interior is completely cooked, the outside of the meat will be overcooked. Good chefs are able to get the thermal inertia of the meat to work in their favor.

During heat treatment, the temperature of the parts will lag behind that of the air in the furnace, since the parts have much higher thermal mass. They will not reach temperature until after the air has reached the prescribed temperature. Therefore, it is important to put a monitoring thermocouple in with the parts, to ensure that you are monitoring the temperature of the parts, and not that of the air. Furthermore, when the heat is turned off and the parts are allowed to cool before removal, the parts will lag behind the air temperature when cooling. This is why it is better to choose heat treat profiles that are relatively flat, with large margins of error, when heat treating parts with a large thermal mass.

If you are must perform a higher temperature heat treatment that requires more precise timing, it is best to use as low a thermal mass as possible for the parts, and to increase the thermal mass of the heat treating medium. In this case, molten salt baths meet this requirement best.

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