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Equipment & Gear

**Common Materials of Cookware**

by Michael Chu

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[Normal view](http://www.cookingforengineers.com/article/120/Common-Materials-of-Cookware)

Over the last year, I've received several requests to write an article on cookware. This is a huge subject, and I've been struggling to figure out a way to present the information accurately and concisely. I decided to divide the information up into separate articles and focus this one on some common materials used in the construction of cookware. I also had to decide how much science and math to include. After some thought on the subject, since this site is called "Cooking For Engineers" and not "Cooking for Physicists", I've decided to include enough information that my readers will grasp the concepts without actually doing any derivations (perhaps this could be a future article). Also, since this article is a bit long and relatively complicated, if I've made any mistakes, please let me know so I can correct them as soon as possible.

The selection of pots and pans can be a complicated affair. The shape of the cooking surface and handle(s), materials used in its construction, the intended purpose of the utensil's design, and its flexibility of use in the kitchen all are important factors in choosing cookware. Understanding the materials used is a good first step in understanding how cookware works and what factors may be important to your cooking style.

**Basic principles**
The purpose of cookware is to impart energy to ingredients. In America, the energy comes mainly in two forms: burning natural gas or propane gas and electrical resistivity. In both methods, the source of the heat is not uniformly spread over the pan. In a gas stove, the gas come out at regular intervals and forms a ring of individual flames. The heating elements of an electric range are designed to cover as much area as possible, but still have patterns (usually spirals) where there is no heat. Because the heat is not applied evenly, the cook must be aware of this and either compensate with cooking technique or through cookware.

High quality cookware should not only be durable, but also take the energy from the heat source and effectively transmit this energy to the ingredients. There are several factors that affect this capability. The two most important factors are thermal conductivity and heat capacity. Almost all discussions concerning the materials used in cookware are focused on these two factors.

*Thermal conductivity*
In short, the thermal conductivity of a material is how readily that material absorbs and transmits (releases) energy. When the fire or heating element of a range comes in contact to a pan, the energy from the heat source is transmitted to the pan. This increases the internal kinetic energy of the pan (commonly called "heating up"). The heated material then transmits the energy to nearby materials that are at a lower average molecular kinetic energy level (at a lower temperature than the material). The higher the thermal conductivity of the material, the faster it will heat up and also, the faster the heated area will spread to unheated areas of the same piece of material.

For example, if we placed a large sheet of stainless steel (fairly low thermal conductivity as cooking materials go) on a burner and turned on the burner, the area directly under the burner would get hot while the rest of the sheet slowly heats up. The burner imparts heat quickly only to the region of steel directly over it. The rest of the pan heats up from the conduction of the heat from that spot. When the outer edges of the sheet have reached a hot temperature, the spot directly over the burner would be extremely hot. The figure below shows an example of the temperature of the sheet of steel over a gas burner. The hottest parts are shown in white, hot is red and cool is blue.


One solution to this problem is to make the sheet thicker. When heating a thick piece of steel (instead of a thin sheet), the bottom surface of the steel does not have the same temperature pattern as the top surface. Because the top surface is a greater distance from the heating element, the energy needs to conduct from the bottom to the top (just like the energy conducts outwards). The top surface of the steel is more evenly heated in this case. The figure below shows the thick sheet of steel after it has been sliced so the center of the front edge is where the burner heat touches the bottom of the sheet. The hot spot (white) is reduced by the time the heat conducts to the top surface of the sheet. Where the sheet is being heated, the temperature is more uniform now, but we still have uneven heating with this material.


For this reason, the thicker the steel, the less variation in temperature on the top surface. Unfortunately, low thermal conductivity means it a lot of energy needs to be imparted to the bottom of the steel in order to get the top hot. So a pan made of a low thermally conductive material will take a longer time to reach cooking temperatures. In fact, materials with low thermal conductivity take longer to react to any change in temperature, so the thermal response of the pan would also be slow. (Thermal response is how quickly the surface temperature of the pan reacts to when we increase or decrease the flame of the burner.)

In most cooking applications, it is desirable to have the utensil heat up quickly, not develop hot spots, and react to changes we make to the range controls. Materials with high thermal conductivity fulfill our needs because they transmit heat quickly resulting in fast response to thermal changes and even distribution of the internal kinetic energy.


Here is a list of some common materials used in cookware and their respective thermal conductivity:

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| **Material** | **Thermal conductivity** |
| Copper | 401 W/m\*K |
| Aluminum | 237 W/m\*K |
| Cast Iron | 80 W/m\*K |
| Carbon steel | 51 W/m\*K |
| Stainless steel | 16 W/m\*K |

*Heat capacity*
The amount of internal kinetic energy stored in a material can be referred to as it's heat capacity. This isn't the same thing as temperature, which is the average molecular kinetic energy within the material. For example, a kg of water at 100°F contains more energy than a kg of steel at 100°F. While thermal conductivity describes the materials ability to absorb energy, heat capacity is the amount of energy that is needed to raise or lower the temperature of the material. The molecular composition of some materials is such that as they absorb energy, much of it gets converted into potential energy and only a small amount increases the molecular kinetic energy (water is a common example). Other materials, like most metals, increase their molecular kinetic energy readily and do not store much of the absorbed energy as potential energy. The heat capacity of a material is proportional to its mass. So, a 2 kg piece of steel has double the heat capacity of a 1 kg piece of steel (make sense, right?).

What this means is that cookware made of materials with high heat capacity, will take longer to heat up, but will also have a significant amount of energy stored up when it is hot. When energy is pulled out of the material, the temperature of the material will lower slowly when compared to materials with low heat capacity. Cast iron is often cited as an example of a high heat capacity cookware material. The specific heat (the heat capacity of a material for a given mass) of cast iron is half of aluminum's specific heat, but because cast iron cookware is generally several times the mass of aluminum cookware, it has a much higher heat capacity.

The thickness of metals used in the construction of cookware are often sited by the manufacturer (for example, 3 mm aluminum), but since heat capacity is a function of the mass of the material, density must be known to make comparisons between cookware of different materials.

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| **Material** | **Specific Heat** | **Density** |
| Aluminum | 910 J/kg\*K | 2600 kg/m3 |
| Stainless Steel | 500 J/kg\*K | 7500 - 8000 kg/m3 |
| Carbon Steel | 500 J/kg\*K | 7500 - 8000 kg/m3 |
| Cast Iron | 460 J/kg\*K | 7900 kg/m3 |
| Copper | 390 J/kg\*K | 8900 kg/m3 |

Looking at the table above, if you multiply specific heat with density, you'll find that the heat capacity per unit volume of steel, cast iron, and copper are about 1.5 times that of aluminum. This means, to achieve the same heat capacity in an aluminum pan as in stainless steel pan, the aluminum pan needs to be 1.5 times as thick (assuming the other pan dimensions are the same).

*Pulling it together: thermal diffusivity*
If you've been paying attention, you'll realize that I've misled you when I discussed thermal conductivity. Thermal conductivity alone does not determine how fast the pan will heat up (and also how evenly it will heat). In fact, the heat capacity plays a role in determining this as well. Wouldn't it be great if we had a single number that told us at what rate heat would transfer through and spread out in the material? There is, it's called the thermal diffusivity of a material and is simply the thermal conductivity divided by the unit heat capacity (specific heat times density). Let's take a look at how the materials stack up:

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| **Material** | **Thermal diffusivity** |
| Copper | 120 \* 10-6 m2/s |
| Aluminum | 100 \* 10-6 m2/s |
| Cast Iron | 22 \* 10-6 m2/s |
| Carbon Steel | 14 \* 10-6 m2/s |
| Stainless Steel | 4.3 \* 10-6 m2/s |

Without additional calculations based on the [heat conduction equation](http://scienceworld.wolfram.com/physics/HeatConductionEquation.html), there is very little that we can do with this table of values, except compare the materials against each other. It is clear, however, that the best performing materials (in terms of dishing out energy) are copper and aluminum. This leads us to our final consideration: reactivity.

*Reactivity*
Not only do we have to concern ourselves with the thermal properties of materials, but we need to make sure that the materials we use in our cookware do not harm us or adversely affect the taste of our food (you decide which is worse). For this reason, in addition to the high thermal diffusivity, we would also like a non-reactive material. Unfortunately, both copper and aluminum react readily to foods. (Copper, when ingested in quantity or consistently, can cause liver, stomach, and kidney problems as well as anemia. Also, aluminum has long been suspected of contributing to Alzheimer's disease. Oh, every cookbook mentions, at this point in the discussion, that the occasional foamed egg white whipped in a copper bowl is not enough to harm you - but refrain from cooking every day on exposed copper.) Stainless steel, the least reactive of all popular materials used in cookware, also has the worst thermal diffusivity.

It seems that today, physics is not our friend. But, through the magic of cookware companies wanting to find ways to charge us lots of money, solutions have been devised to enable us to enjoy cookware made of materials with high thermal diffusivity and low reactivity. By combining the non-reactive surface of stainless steel with the thermal properties of copper or aluminum, you get the best of both worlds. There are several variations on this theme: steel- or tin-lined copper, stainless steel with aluminum or copper disk, stainless steel cladded aluminum, and stainless steel cladded copper. The table below summarizes my subjective assessment of the effectiveness of various material combinations (they are listed in order from most effective to least):

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| **Rank** | **Composition** | **Comments** |
| 1 | Copper with tin lining | Highest response; tin lining can be finicky can be susceptible to melting; copper exterior requires more care |
| 2 | Copper with stainless steel lining | Copper exterior requires more care but imparts the utensil with copper's excellent thermal properties |
| 3 | Aluminum with stainless steel lining | Thick aluminum provides excellent thermal response to thin steel interior |
| 4 | Copper fully clad by stainless steel | Copper layer may be thinner than copper with stainless steel lining; exterior and interior are durable and easy to maintain |
| Aluminum fully clad by stainless steel | Aluminum layer may be thinner than aluminum with stainless steel lining; exterior and interior are durable and easy to maintain |
| Aluminum with stainless steel lining and copper exterior | Same performance as cladded aluminum, but with the difficulties in maintaining copper |
| 5 | Stainless steel with copper disk | Curved edge of the bottom causes the disk to not come into full contact with the complete bottom of the pan resulting in inferior heat conduction as compared to cladded copper |
| Stainless steel with aluminum disk | Same as stainless steel with copper disk |

Previously, I mentioned that cast iron has a large heat capacity as compared to the other materials (mostly because of the mass used when making the cookware). Because of this attribute, cast iron gets a special place in the kitchen. When the cooking task requires the ability to maintain consistent heat (and ample amounts of it), nothing beats cast iron. Because cast iron can react with acidic foods and ingredients that are cooked for a long time, cast iron cookware is seasoned - a process by which layers of fat are slowly cooked into the porous iron until the fat polymerizes forming a protective barrier (and makes the utensil relatively non-stick).

**Common materials and how they compare**
Now that we've looked at the important properties in selecting cookware material, let's take a look at each of the common materials used in cookware.

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| **Copper** |
| **Description** | Copper is a soft (scratches easily) but durable (will last a lifetime) material that has great thermal properties. The material is prone to oxidation but with care, will retain its beauty indefinitely. |
| **Pros** | * High thermal diffusivity
* With enough thickness, pans heat extremely evenly
* Extremely responsive
 |
| **Cons** | * Heavy
* Extremely expensive
* Copper surface can tarnish or scratch
* Pan may cool too fast after removal from heat (due to extremely high thermal conductivity)
* Cooking directly on copper may result in undesirable levels of copper intake
 |
| **Best uses** | * When lined with tin, nickel, or stainless steel, excellent for all stovetop uses.
 |
| **Care** | * Hand wash with a non-abrasive detergent and hand dry
* Regularly use polish on exposed copper to preserve shine
 |
| **Examples** | * [Mauviel Cuprinox](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/13363491/ref=br_bx_c_1_1) (extremely expensive copper with inner stainless steel lining)
* [Mauviel Pastry & Chocolate](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/13363531) (extremely expensive copper pans and bowls designed for pastry making)
* [All-Clad Copper Core](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/556938) (Stainless steel clad copper - easier maintenance with the performance of copper)
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| **Aluminum** |
| **Description** | Plain aluminum utensils are low-cost, light-weight, and thermally responsive - but it's reactive. Teflon coated aluminum utensils are low-cost and both non-stick & non-reactive. Anondized aluminum has been treated to develop an aluminum oxide (extremely hard and non-reactive) coating on the surface of the utensil. Clad or lined aluminum has had stainless steel bonded to the interior of the utensil to form a non-reactive surface. |
| **Pros** | * Extremely low cost if plain or teflon lined; moderated priced when anondized
* Great thermal properties
 |
| **Cons** | * Very expensive if stainless steel lined or clad
* highly reactive to acid ingredients (and somewhat reactive to alkaline as well)
* Lower density may require thicker construction to increase heat capacity
* Unless anondized or lined or clad with stainless steel, may warp under high heat
* Unless anondized or clad, aluminum is prone to scratching.
 |
| **Best uses** | * Plain aluminum - good for non-acid foods, like boiling stock or cooking pasta
* Coated aluminum - excellent for all purposes if aluminum is fairly thick
 |
| **Care** | Hand-wash with a mild detergent and washcloth or sponge. |
| **Examples** | * [Admiral Craft Saucepans](http://www.amazon.com/exec/obidos/ASIN/B00063863O/ref%3Dnosim/themichaelupdate) (low cost aluminum pans)
* [Admiral Craft Fry pans](http://www.amazon.com/exec/obidos/ASIN/B00063899K/ref%3Dnosim/themichaelupdate) (low cost aluminum non-stick pans)
* [Calphalon Commercial](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/573766) (moderately priced anondized aluminum)
* [All-Clad LTD](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/556944) (very expensive aluminum with stainless steel lining)
* [All-Clad Stainless](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/556948) (very expensive stainless steel cladded aluminum)
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| **Cast iron** |
| **Description** | Cast iron is composed on iron, carbon (more than carbon steel), and trace elements found in common clays. The iron is melted down and poured into a sand or clay mold to form the utensil. Enameled cast iron has a thin but durable nonreactive layer of glass fused to the surface of the utensil. |
| **Pros** | * Plain cast iron is low cost
* Manufacturing process results in thick and dense cookware for unparalleled heat capacity
* Thickness also results in even heating
 |
| **Cons** | * Enameled cast iron can be expensive (although some are moderately priced)
* High heat capacity means the utensil takes longer to heat up
* Although extremely hard, can crack or fracture if dropped or thermally shocked (pouring cold water into a hot pot)
 |
| **Best uses** | * Traditional woks (plain cast iron), skillets, Dutch ovens
* Southern cooking
 |
| **Care** | Plain cast iron should be seasoned before first use and as needed. A seasoned utensil should receive minimal contact to soap or detergent. Wash by soaking in warm water for a few minutes and repeatedly scrubbing with salt and rinsing until salt remains white (usually one scrubbing is does it). Dry with a cloth and heat over low heat briefly to evaporate all moisture. For enameled cast iron, hand wash in hot soapy water. |
| **Examples** | * [Lodge Logic](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/13949681) (low cost cast iron)
* [Wok Shop](http://www.amazon.com/exec/obidos/ASIN/B00012F3F4/ref%3Dnosim/themichaelupdate) (low cost cast iron traditional Cantonese wok; this wok is awesome, but its rounded bottom works best on gas stoves)
* [Le Creuset](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/297815/ref=k_i_bra_l_4) (expensive enameled cast iron)
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| **Carbon steel** |
| **Description** | Carbon steel contains less carbon than cast iron and is formed and pressed from sheets instead of being casted. It can be annealed (heating the metal until its molecular structure realigns to alleviate internal stresses and then specially cooled to preserve the new structure) to form blue steel (or black steel), a harder and less reactive material. Carbon steel can also be enamel coated. |
| **Pros** | * All variations are usually low cost
* Fast seasoning process for carbon steel; enameled carbon steel and blue or black steel does not need seasoning
 |
| **Cons** | * Poor thermal properties means slow heat up and uneven temperatures.
* Thin and light (this might be a pro for some people) which results in very little heat capacity
 |
| **Best uses** | * Fry pans, saute pans, woks
 |
| **Care** | Should be seasoned before first use. Care for as if it was cast iron. If desired, pan can be washed in soapy water, scoured, and reseasoned quickly (15 minute seasoning) because of its less porous nature than cast iron. |
| **Examples** | * [Gibson Red Parker](http://www.amazon.com/exec/obidos/ASIN/B0009QMZDU/ref%3Dnosim/themichaelupdate) (extremely low cost carbon steel non-stick)
* [The Wok Shop](http://www.amazon.com/exec/obidos/ASIN/B00012F3AO/ref%3Dnosim/themichaelupdate) (low cost carbon steel; also a traditional Cantonese wok)
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| **Stainless steel** |
| **Description** | Mixing steel with chromium and nickel (18/8 stainless steel is 18% chromium and 8% nickel while 18/10 has 10% nickel) produces a corrosion resistance steel that is both hard and easy to maintain a shine. Disks of copper or aluminum can be fused to the stainless steel cookware to enhance its thermal properties. Stainless steel can also be used to line copper or aluminum utensils as well as cladding aluminum or copper (see aluminum and copper cookware summaries above). |
| **Pros** | * Plain stainless steel and stainless steel with aluminum or copper disks are low cost to moderately priced
* Shiny surface makes it easy to see how your food is browning
* Corrosion resistant and easy to clean
* With a thick aluminum or copper disk or clad around a core, stainless steel becomes one of the best materials to cook in (not just for its thermal properties, but as well as durability, ease of care, and visual control of cooking - all the benefits of stainless steel with very little of its drawbacks)
 |
| **Cons** | * Plain stainless steel: worst material to cook on (in terms of thermal properties)
* Salt may cause pitting over time unless added to boiling liquid
 |
| **Best uses** | * Plain stainless steel: boiling water (steaming is okay) and non-cooking related tasks (mixing bowls, storage containers, etc.)
* Stainless steel with copper or aluminum disk: great for all purposes if disk is well bonded and of a fair thickness
 |
| **Care** | Hand wash with mild detergent. Use gentle abrasives as needed. |
| **Examples** | * [Cooktop Essentials](http://www.walmart.com/catalog/product.gsp?product_id=3884617)

[(extremely low cost stainless steel)](http://www.walmart.com/catalog/product.gsp?product_id=3884617)* [Revere Copper Clad](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/655892/ref=br_bx_c_1_0) (low cost stainless steel with misleading marketing name; the copper lining at the bottom of these pans are too thin to provide any thermal benefits)
* [T-Fal (Tefal)](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/585550/ref=br_bx_c_1_1) (low cost stainless steel non-stick with copper marketing gimmick - again, too thin)
* [Farberware Classic](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/574596/ref=br_bx_c_1_1) (low to moderate cost stainless steel with aluminum disk embedded inside the stainless steel exterior)
* [Circulon Steel](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/1085474) (moderate cost stainless steel with aluminum disk)
* [Scanpan Steel](http://www.amazon.com/exec/obidos/ASIN/B0000CDUWG/ref%3Dnosim/themichaelupdate) (moderate cost stainless steel with 6.8 mm (!) aluminum disk)
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My personal favorites for cookware materials are stainless steel clad aluminum or copper and cast iron (for skillets and woks). The stainless steel clad utensils perform well, are easy to clean, and look beautiful. Of course, not all stainless steel clad aluminum (sometimes called tri-ply or five-ply depending on construction) are the same. All-Clad has definitely earned their reputation as quite possibly the best general use cookware money can buy, but it's a lot of money to be spending. All-Clad rarely goes on sale, but other reputable brands, such as Calphalon, have [clad lines](http://www.amazon.com/exec/obidos/redirect?tag=themichaelupdate&path=tg/browse/-/573808) as well - and they are more likely to have their product lines go on sale. Keep checking the [Cooking For Engineers Deals Blog](http://www.cookingforengineers.com/deals) to see when deals do come up.