Test of Materials for Downdraft Grates

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Introduction

Grates in wood burning cook stoves are useful for improving combustion and increasing performance. Grates support the burning coals and allow air to pass freely through the fuelbed.

Most stoves operate in the normal updraft mode in which air passes up through the grate and rises through the coals and the burning wood on top. Temperatures at the top of these grates tend to be about 800° C. Fresh air passing through the grate limits the temperature and the grate can be made of common materials like cast iron or mild steel.

Downdraft stoves operate differently. Air is sucked downward through the fire and the flames and heat from the burning wood and coals impinge directly on the grate. As a result the temperature of the grate tends to be much higher (typically 200º to 300° C higher). Many materials which would serve well at lower temperatures tend to melt or degrade rapidly when exposed to the higher temperatures of a downdraft grate.

Downdraft stoves appear to have certain advantages over normal stoves. Particulate levels can be very low and the temperatures of combustion gasses may be higher than in many updraft stoves. The development of an affordable durable downdraft grate might help make downdraft stoves a practical option for use in developing countries.

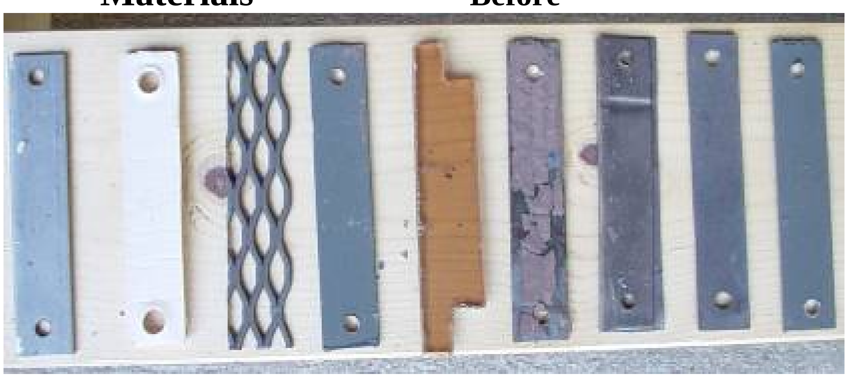
In this experiment 9 different possible materials were incorporated in a grate for a downdraft stove and used for a period of 10+ hours. The grate was then disassembled and the materials were then examined for weight loss and structural integrity.

A caveat on measurement of temperatures

Temperatures in this experiment were made using a K type thermocouple encased in a 1/8” incanel sheath. Thermocouple measurements of temperatures in stoves can be problematic mainly due to radiation to and from the point being measured. This problem is discussed in detail by Bryden and Gent in their article, “How Flame Temperature Measurement is Affected by Radiant Heat Transfer”. Actual temperatures can be higher or lower than the measured temperature by as much as several hundred degrees. Reported temperatures should be viewed as relative rather than absolute. What is important to note is that the materials were exposed to temperatures representative of downdraft stoves and that those temperatures are higher than in updraft stoves with grates.

Materials

Before



Test bars were made of from the following materials (left to right);
(1) Mild steel (2) flameware clay (3) RA330 steel (4) mild steel with W204 coating (5) Corning Visionware (6) mild steel with ITC213 coating (7) 304 stainless (8) cast iron (9) mild steel with ceramic glaze

After

Assembled Grate

before	after
	

Test Stove

The test stove was constructed of vermiculite/clay insulative ceramic. The design of the combustion chamber was based on a design by Peter Verhaart.

Procedure

Each bar of test material was weighed and measured. Test bars were assembled into a grate and installed in the stove. The stove was used in a series of 5 tests (three runs each) in a separate experiment. Measurements of temperature in the grate (half way down between the bars) were taken periodically. The highest temperature observed was 1109° C and the lowest was 919º C. The average was 1036° C.

At the end of the series of tests the grate was extracted and disassembled. Each bar was then weighed again to determine weight loss.

Total burn time for the stove was 10 hours and 40 minutes.

Calculations

Weight loss for each bar was determined by simple subtraction. The surface area and volume of each bar was calculated. It was assumed that weight loss was proportional to surface area and a loss /cm2 was determined for each bar. The mild steel bars all had the same dimensions but the other bars were slightly different. A calculation was made to determine what the weight of the bars would have been if they were all the same dimension. The surface area of this "standard" dimension times the weight loss/cm2 for the material gave the theoretical weight loss for a bar of that material. A percentage weight loss per hour was calculated based on the total time of testing (10hours and 40 minutes).

To help visualize how long these materials might last, a final calculation of (weight of bar)/(wt. loss per hour) was made to determine how long it might take to completely consume the bar. This calculation is not strictly accurate since it ignores the fact that the dimensions of the bar change as it is consumed. It also ignores the fact that the bar would fail when only partially consumed. This calculation does however provide some basis for comparing the durability of materials.

Results

Material	wt. start	wt. loss	surf area	vol. cc	loss/cm2	adj. wt	adj. loss	%loss/hr	max hours service
RA330 alloy	24.6	0	38.02	3.25	0.0000	59.1	0.0	0.00%	no limit
304 stainless	32.8	0.4	126.75	3.13	0.0032	82.0	0.2	0.03%	3953
Vision Ware	47.4	0.2	84.96	20.16	0.0024	18.4	0.2	0.08%	1187
flameware clay	27.4	0.2	74.50	12.50	0.0027	17.1	0.2	0.10%	971
glazed steel	62.8	10.6	70.00	7.81	0.1514	62.8	10.6	1.58%	63
ITC213 coated steel	62.6	17.6	70.00	7.81	0.2514	62.6	17.6	2.64%	38
W209 coated steel	62.2	18.6	70.00	7.81	0.2657	62.2	18.6	2.81%	36
mild steel	61.2	19	70.00	7.81	0.2714	61.2	19.0	2.92%	34
"cast iron"	45	-4	68.50	6.25	-0.0584	56.3	-4.1	-0.68%	N/A

Discussion of Materials

RA 330 Alloy

RA330 is heat resistant steel used in kilns and annealing ovens. The high level of chromium in this alloy makes it very heat resistant but also relatively expensive. RA330 expanded metal is commonly used to make the baskets which are used to hold metal parts being heat treated. The piece used in this experiment was cut from a larger sample sent to Aprovecho by Rolled Alloys Company. It is not commonly available and must be specially ordered. It remained strong even at high temperature and was virtually untouched by the heat and emissions involved in this trial. It would be suitable for grates in all aspects except perhaps cost.

304 Stainless Steel

This is common stainless steel. This sample was cut from a scrap piece of stainless and doubled over to form a bar. This sample fared better than expected and was the most durable material after RA 330. Thin 304 has been used for combustion chambers in rocket stoves but has eventually burned out and is considered unsuitable for that purpose.

Thicker bars of 304 might be suitable for downdraft grates if it were possible to replace the bars periodically.

Corning Vision Ware

Visionware is the brown tinted crystalline glass product used to produce pots and dishes intended for direct use in ovens. The formula is proprietary but it probably contains lithium minerals which limit thermal expansion and make it resistant to thermal shock. The sample tested was cut from the bottom of a casserole dish (from the local thrift store) and ground to shape. This material seemed fairly tough and held up to the high temperatures encountered. When the grate was disassembled this piece was wedged in by adjoining bars which had contracted and the visionware bar was broken during extraction. A few small chips may have been lost before weighing and this may account for the apparent weight loss. This material might actually be as suitable as 330 and would probably be much cheaper. The bar was transformed from being transparent to being opaque during the test. This change might represent a recrystalization of the material into larger crystals which could limit its longevity.

Flameware Clay

Ceramic bars were made from a specialty clay called “flameware” which was provided by Seattle Pottery Supply. The formula for this clay is proprietary but the manufacturers say it does contain spodumene which is a lithium mineral. This clay is only slightly more expensive than most other pottery clays. The bars were fired in a pottery kiln to cone 8 before being installed in the grate. This material was somewhat more brittle than the visionware but is still fairly strong. This bar was also broken during extraction and it is possible that not all the material was recovered for weighing so actual durability could be longer than indicated.

Mild Steel

Mild steel flatbar was purchased from a hardware store and sawn into 4 identical 125mm long pieces. All pieces were baked in an oven at 450° F to remove any residual oils. This piece was mounted in the grate with no further treatment. The other three pieces were given special coatings which were supposed to protect them from heat and prevent degradation. The maximum service life of this untreated mild steel was only 34 hours but the treated pieces were only marginally better.

Glazed Mild Steel

This piece of mild steel was coated with Duncan SY553 pottery glaze and fired to cone 04 (about 1050° C). Better results might have been obtained if an enameling frit had been used instead. Most of the glaze melted off during the trial but the maximum service life of the bar was still almost double that of untreated mild steel.

ITC 213 Coated Mild Steel

ITC 213 is a refractory coating designed to protect metal parts in pottery kilns. In theory this coating has high emissivity which radiates heat back into the combustion chamber rather than allowing it to pass through into the metal. The coating was applied according to manufacturer’s instructions. This coating had a tendency to flake off from the mild steel and by the end of the trial almost all of the coating had separated. The service life of this bar was little better than untreated mild steel. The high cost of this coating also discourages its use in grates.

W 209 Coated Mild Steel

Insulcoat W-209 is a product of NIC Industries Inc. and is designed to protect automotive exhaust systems and industrial equipment from excessive heat. It is rated to protect parts up to 1800º F (1000° C). The coating was applied according to manufacturer’s instructions and cured at 700º F for 1 hour. This coating adhered well at lower temperatures but tended to spall and flake off during the trial. Service life of this bar was also little better than uncoated mild steel.

Cast Iron

"Cast Iron" is a generic term for cast formed alloys containing varying quantities of iron, carbon, and silica. The bar used in this test was cut from the bottom of a cast iron frying pan (from the thrift store). This bar became deformed and twisted during the trial. For this reason it would be unsuitable for downdraft grates. This bar actually showed an increase in weight during the trial. The obvious and most probable explanation is that a mistake was made during the initial weighing of the bar. It is also possible that mineral ash from the fire coated the bar causing an increase in weight. The final possibility is that the iron lattice of the hot bar actually incorporated extra carbon into its structure from the burning charcoal layer above it. Cast iron is an excellent material for grates in ordinary updraft grates but does not appear to stand up to the higher temperatures of downdraft stoves.

Conclusions and Recommendations

RA330 alloy was the only material tested which was unaffected by the trial. 304 stainless might be suitable if it were replaced periodically. Corning visionware might be a suitable material for grates but is not available in a usable form at this time. Flameware clay can be used to form grates and is a promising material.

Another heat resistant alloy, 309 stainless was unavailable for this test. It is cheaper than RA330 and more heat resistant than 304. It is recommended for service up to 1100° C. It might be the best compromise between cost and durability for use in downdraft grates.

Common earthenware ceramic is often used to form grates in charcoal burners and portable stoves. This material can serve quite well in an updraft stove but in most cases these grates are simply round holes punched in a clay plate. The ratio of open area to solid area must be kept low so that the plate retains strength. It is doubtful that strong plates of this type could be produced with enough open area to function well in a downdraft mode.

Cast iron is unsuitable for use in downdraft grates.

The failure of all three protective coatings on mild steel was a great disappointment. The development of a successful protective coating for inexpensive metals would be a great boon to the development of improved cookstoves.

References

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