Burn-resistant metal alloys that also have a high tensile strength are described. The alloys generally include about 55 to about 75 weight percent nickel, about 12 to about 17 weight percent cobalt, about 4 to about 16 weight percent chromium, about 1 to about 4 weight percent aluminum, and about 1 to about 4 weight percent titanium.
FIG. 1

Extending Threshold Pressure, psia

Room Temperature Tensile Strength, ksi

MA-754™
Monel K-500™
Haynes 214™
EX 1
EX 2
Alloy 625
Waspaloy™
Alloy 718
BURN-RESISTANT AND HIGH TENSILE STRENGTH METAL ALLOYS

CROSS-REFERENCE TO RELATED APPLICATIONS


FIELD

[0002] This relates generally to metal alloys and more particularly to nickel-based alloys that are resistant to burning in oxygen-enriched environments and which have sufficient strength for structural applications.

BACKGROUND

[0003] The current and proposed use of oxygen-rich and full-flow staged combustion rocket engine cycles imposes a significant challenge on the selection of materials for preburner and turbomachinery components. Most materials burn in the high pressure, flowing gaseous oxygen environment to which these components would be subjected. A major challenge for compatibility in these environments is the selection of structural materials which will not sustain combustion, i.e., which are substantially burn resistant. Material selection options include protective coatings on materials that do not have inherent burn resistance to preclude burning within the given operating environment. The desired approach is to avoid the use of coatings and opt for materials that can survive in the operating environment, thereby increasing safety and reliability factors. In addition, selecting high strength materials allows for a streamlined design which is lighter weight and higher performance.

[0004] U.S. Pat. Nos. 4,461,542 and 4,671,931, the entire specifications of which are incorporated herein by reference, disclose a nickel-chromium-aluminum-iron alloy commercially available under the trade name Haynes® 214™, which was developed as a high-temperature, oxidation-resistant alloy. Although Haynes® 214™ is somewhat burn-resistant, it is substantially limited in structural applications due to its relatively low strength, and is therefore undesirable for rocket engine preburner and turbomachinery applications.

[0005] Another material includes Monel Alloy K-500™, which is a nonferrous alloy containing mainly nickel, copper, and aluminum. It is corrosion resistant and capable of hardening by heat treatment. Monel Alloy K-500™ has been used for gears, chains, and certain structural members in aircraft that are subjected to corrosive attacks. Although Monel Alloy K-500™ is burn resistant, it lacks desirable strength for high stress and high temperature rocket engine applications.

[0006] Another is Inconel MA 754™, which is an oxide dispersion strengthened nickel-chromium-iron-yttria-titanium-aluminum alloy which possesses high-temperature strength and creep resistance and has been used in gas turbine engineering and thermal processing applications. As with the previously described materials, it also does not possess desirable strength for high stress environments.

[0007] Finally, other materials such as the alloy 625 or Waspaloy™ may have sufficient tensile strength for use in these rocket engine components or other high stress applications, however, they are limited in other key areas. In particular, these metal alloys do not exhibit sufficient burn resistance for use in the elevated temperature, high pressure oxygen environments. As a result, typical rocket engine structural materials such as Waspaloy™ are not considered viable candidate materials for the rocket engine applications of interest. Therefore, there continues to exist a need for superior burn resistant and high tensile strength metal alloys for use in high temperature and high pressure oxygen environments. The preburner and hot turbine components in full-flow and oxygen-rich rocket engines produce both high temperature and high pressure oxygen environments and they are subjected to very high structural loads. Thus, it is desirable that the materials chosen for these components possess both excellent resistance to burning and high tensile strength to survive and perform in this challenging environment. Such materials, are not generally known in the art.

SUMMARY

[0009] According to various embodiments, an alloy that is resistant to burning in oxygen-rich environments yet is useful in structural applications is disclosed. The alloy may also be adaptable for use in oxygen-rich rocket engines. Moreover, the alloy may be useful in structural applications at operating temperatures ranging from room temperature to approximately 1200°F.

[0010] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

DESCRIPTION OF THE DRAWINGS

[0011] The present invention will become more fully understood from the detailed description and the accompanying drawings wherein:

[0012] FIG. 1 is a graphical illustration of the Extinguishing Combustion Threshold as a function of tensile strength for prior art and embodiments of the present invention.

DETAILED DESCRIPTION OF VARIOUS EMBODIMENTS

[0013] The following description of various embodiments is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses.

[0014] An alloy in various applications generally requires both a high burn resistance, as described herein, and a high structural integrity or strength. For example, a metal alloy may be required to include a burn resistance of at least 1,000 psi of oxygen and a tensile strength of about 140 thousand pounds per square inch (ksi). Nevertheless, many alloys generally include at most one of several desirable characteristics. Various alloys, however, may include both a selected burn resistance and a selected strength. For example, a nickel based alloy may include about 55 to about 75 weight percent nickel; about 12 to about 17 weight percent cobalt, but may also include less than 10 weight percent, such as about 10 to 11 weight percent cobalt; about 4 to about 16 weight percent chromium; about 1 to about 4 weight percent aluminum; and about 1 to about 4 weight percent titanium. Various embodiments may also comprise various other minor components.

[0015] According to various embodiments, the alloys may also contain manganese in amounts of about 0.15 to about
0.25 weight percent; silicon; carbon in amounts of about 0.01 to about 0.5 weight percent; boron in amounts of about 0.003 to about 0.009 weight percent; and zirconium in amounts of about 0.02 to about 0.07 weight percent.

[0016] The nickel component may help ensure a selected burn resistance, and may be superior in terms of burn resistance relative to most other elemental metals that were previously used. Various embodiments may comprise levels of nickel in amounts of at least 50% weight. This level of nickel is generally used to maintain superior burn resistance. Various embodiments may also comprise nickel weight percent in the range of about 70 to about 75.

[0017] Cobalt, without being bound by the theory, may act as a solid solution strengthener in the nickel matrix while maintaining superior burn resistance. For example, cobalt may act as holding the various elements or components of the alloy together in solution. It may assist in obtaining a selected strength of the final alloy, in selected percentages or ratios and help in ensuring a selected burn resistance. Cobalt weight percent may be in the range of about 12 to about 17 of the alloy.

[0018] Chromium may be included to provide a selected oxidation resistance. Various embodiments of the present invention comprise about 15 weight percent of chromium and may help maintain the alloy’s selected burn resistance. Various embodiments of the alloy generally include chromium weight percent of about 6 to about 15, but may also be included as about 7-9 weight percent.

[0019] As discussed above, it is desirable to provide an alloy that includes a selected strength. Although strengths of an alloy may be achieved by selected elemental components, strengths of an alloy may also be achieved by forming specific or selected constructs or formations within the alloy itself. For example, gamma prime formations within an alloy can increase its strength and assist in achieving an alloy that includes a selected strength. Without being bound by the theory, gamma prime formations may also reduce burn resistance. Therefore, it is desirable to provide a weight percent of gamma prime formers that may achieve a selected strength without substantially reducing a burn resistance of a final alloy. Determining and achieving such a composition for an alloy, however, may be difficult and depend upon other selected elemental components.

[0020] Various gamma prime formers may be known. Aluminum may be one selected gamma prime former. The aluminum content may also aid in the oxidation resistance of the alloy and selected amounts may also be chosen to assist in maintaining superior burn resistance. Further, the aluminum content may assist in gamma prime formations in the alloy and as such may contribute to the alloy’s gamma prime strengthening mechanism. Aluminum comprises about 1 to about 3 weight percent of the alloy, and may comprise about 1.25 to about 2.75 weight percent.

[0021] Titanium may also be a gamma prime former to increase a selected strength of the final alloy. The titanium content may also contribute to the alloy’s gamma prime strengthening mechanism. Titanium may be present in the range of about 1 to about 4 weight percent, but may also be present at about 2.5 to 4 weight percent.

[0022] As discussed above, it is selected to provide an alloy that includes both a selected strength and a selected burn resistance. As illustrated in the examples below, an increased amount of selected components can decrease one of the selected aspects, that being at least a burn resistance or a strength. Therefore, providing the various elemental components in selected ranges provides or achieves the selected aspects, such as a selected burn resistance and a selected strength. As further discussed below, providing a selected elemental component in a selected range may increase a strength while decreasing a burn resistance. In addition, providing other elemental components may increase a burn resistance while decreasing a strength. Therefore, it is selected to provide a particular amount of each of the selected elemental components to achieve the selected characteristics of the final alloy such as is not generally known in the art.

[0023] Briefly, the gamma prime formers, such as aluminum and titanium may increase the strength of an alloy while decreasing its burn resistance. Although aluminum may increase the oxidation resistance of a metal alloy, it may decrease the burn resistance of the alloy. Therefore, it may be selected to provide various elemental components in selected ranges such as to achieve both a selected strength and a selected burn resistance.

[0024] Other minor elements such as boron, zirconium, and carbon may be present in the alloy. These additions typically segregate to the grain boundaries and impart strength which can be important during primary and secondary fabrication steps. In addition, these various minor elements may be added to increase strength, decrease oxidation and increase burn resistance. Nevertheless, these elements are added only in amounts and concentrations that do not reduce a characteristic or range, such as a selected burn resistance or a selected strength, of the alloy. In addition, it will be understood that various impurities may be present in a selected alloy that may not affect the characteristics of the final alloy, at least in a negative way. Therefore, various impurities that may not be removed may not interfere with the final characteristics of the alloy but may not be added to achieve a selected characteristic.

[0025] The nickel-based alloys are generally fabricated via a two-step melting sequence which involves vacuum induction melting and vacuum arc remelting. This two-step process yields an alloy ingot which undergoes mechanical work to convert the ingot into billet, bar, sheet or plate.

[0026] The alloys according to various embodiments possess a combination of properties including burn resistance and superior strength in an oxygen-enriched environment as illustrated by the following examples:

Example 1

[0027] An alloy having the weight percent composition of about 71.5 nickel, 16.5 cobalt, 8.0 chromium, 1.5 aluminum and 2.5 titanium was prepared. The alloy has been tested in high-pressure environments generally more harsh than or similar to a full-flow staged combustion and oxygen-rich staged combustion rocket engine. This alloy exhibited both high tensile strength and high burn resistance. The results of the test of Example 1 are plotted in FIG. 1 at data point Ex. 1. The tensile strength of Example 1 alloy is about 170 thousand pounds per square inch and may be high enough for most rocket engine environments in both room temperature and high temperature applications and tests. Furthermore, the Example 1 alloy has a selected burn resistance of at least about 10,000 psi which allows it to survive the high pressure oxygen environment.
Example 2

[0028] An alloy having the weight percent composition of 69.9 nickel, 16.6 cobalt, 8.1 chromium, 1.5 aluminum and 3.9 titanium was prepared. The alloy has been tested in high pressure gaseous oxygen environments generally more harsh than or similar to a full-flow staged combustion and oxygen-rich staged combustion rocket engine. The alloy exhibited both high tensile and high burn resistance. The results of the test of Example 2 are plotted in FIG. 1 at data point Ex. 2. The tensile strength of Example 2 alloy is about 187 thousand pounds per square inch and may be high enough for most rocket engine environments in both room temperature and high temperature applications and tests. Furthermore, the Example 2 alloy has a selected burn resistance of about 7,000 psi which allows it to exist in high pressure oxygen environments.

[0029] In addition to Example 1 and 2 described above, Examples 3-5 were also tested and their compositions are included in Table 1, including the compositions of Example 1 and 2. As can be seen, the various compositions include a weight percentage of nickel of at least about 70 weight percent. Each of the exemplary alloy compositions also include an aluminum weight percent of no more than 1.5 percent. Although an additional amount of aluminum may be provided, as discussed above, various compositional ranges may be selected to achieve selected results. Furthermore, titanium is provided in the various compositions at about 2.5 weight percent and generally no more than about 4 weight percent. As discussed above, the aluminum and titanium are generally gamma prime formers that can increase a selected strength of the alloy. Nevertheless, gamma prime formations can decrease the burn resistance of the selected alloy.

[0030] Each of the exemplary compositions include a tensile strength of at least about 145 thousand pounds per square inch. The strength is achieved while also including a burn resistance of at least about 6,000 psi. It is not generally known in the art to provide a metal alloy which includes both such a high strength and a high burn resistance. Therefore, providing the alloy according to the various embodiments, achieves a result which allows an alloy not including any other coatings or coverings to be provided in harsh environments such as high oxygen flow rocket engine, and maintain both structural strength and integrity and not burn under harsh atmospheres.

### TABLE 1

<table>
<thead>
<tr>
<th>ID</th>
<th>Ni Wt %</th>
<th>Co</th>
<th>Cr</th>
<th>Ti</th>
<th>Al</th>
<th>C</th>
<th>Other</th>
<th>Promoted Combustion Threshold (psi)</th>
<th>Tensile Strength (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex. 1</td>
<td>71.5</td>
<td>16.5</td>
<td>8.0</td>
<td>2.5</td>
<td>1.5</td>
<td></td>
<td></td>
<td>10000</td>
<td>170</td>
</tr>
<tr>
<td>Ex. 2</td>
<td>69.9</td>
<td>16.6</td>
<td>8.1</td>
<td>3.9</td>
<td>1.5</td>
<td></td>
<td></td>
<td>7000</td>
<td>187</td>
</tr>
<tr>
<td>Ex. 3</td>
<td>83.6</td>
<td>8.0</td>
<td>3.1</td>
<td>1.3</td>
<td>4.0</td>
<td></td>
<td></td>
<td>10000</td>
<td>145</td>
</tr>
<tr>
<td>Ex. 4</td>
<td>70.30</td>
<td>16.4</td>
<td>7.7</td>
<td>3.4</td>
<td>1.4</td>
<td>.05</td>
<td></td>
<td>≥6000</td>
<td>195</td>
</tr>
<tr>
<td>Ex. 5</td>
<td>77.2</td>
<td>7.8</td>
<td>3.4</td>
<td>1.4</td>
<td>.04</td>
<td></td>
<td></td>
<td>10000</td>
<td>183</td>
</tr>
</tbody>
</table>

[0031] Contrary to the alloys of the various embodiments included herein, other materials that may be generally known do not achieve such selected characteristics. For example, as illustrated in Table 2, various other generally known alloys which may be known by their trade names Waspaloy®, Haynes® 214™, MA 754®, and Alloy 718®, do not achieve such selected characteristics. As shown in Table 2, each of the compositions may include an alloy which includes a majority of nickel and various other components, such as chromium, titanium or aluminum or combinations thereof. Nevertheless, each of the comparative examples do not achieve the selected results for strength and burn resistance. For example, those that include a tensile strength greater than about 145 thousand pounds per square inch have a very low burn resistance, such as generally below 1,000 psi. Additionally, those that include a burn resistance above about 1,000 psi include a low tensile strength. Therefore, those nickel alloys that include a tensile strength great enough for structural components, such as those including a tensile strength greater than about 145 thousand pounds per square inch, do not include a combustion resistance high enough for selected application, such as rocket engines. In addition, those alloys that do include a high burn resistance do not include a tensile strength great enough for selected structural components.

### TABLE 2

<table>
<thead>
<tr>
<th>Comparative Examples</th>
<th>Promoted Combustion Threshold (psi)</th>
<th>Tensile Strength (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waspaloy</td>
<td>500</td>
<td>185</td>
</tr>
<tr>
<td>Alloy 718</td>
<td>750</td>
<td>208</td>
</tr>
<tr>
<td>Haynes 214</td>
<td>10000</td>
<td>135</td>
</tr>
<tr>
<td>MA 754</td>
<td>10000</td>
<td>140</td>
</tr>
</tbody>
</table>
The Extinguishing Threshold Pressure is the maximum pressure of gaseous oxygen at which the alloy will self-extinguish as measured by the Promoted Combustion test. This test is used to determine if a material, in the configuration of a one-eighth inch rod, will sustain or extinguish combustion in a high pressure, gaseous oxygen environment. It is a test used to screen metals for burn resistance in oxygen.

The tensile strength is determined through a typical tensile test which involves imparting a tensile load on a standardized specimen and determining at what stress the specimen fails. Superior behavior in both tests is desired for oxygen-rich rocket engine applications. Alloys which do not sustain combustion at or above 6000 pounds per square inch (psi) gaseous oxygen and which exhibit as much strength as possible are selected. Alloys with lower strengths may be used in some instances, but the resulting structure generally sacrifices lightweight and high performance properties.

Therefore, it has been found that providing a selected range of various elements in a nickel base alloy can achieve both a high strength and high burn resistance. Moreover, generally specific compositional ranges achieve results including a selected tensile strength and burn resistance that are maximized. For example, in Example 1, including a compositional range of less than about 75 weight percent nickel and between about 2 and about 3 percent titanium and about 1 and about 2 weight percent aluminum may form an alloy that includes a burn resistance of about 10,000 psi and a tensile strength of about 170 thousand pounds per square inch. This may also be compared to Example 2 that includes about 73 weight percent nickel and a larger amount of titanium, of about 4 weight percent that includes a tensile strength that is higher, about 187 thousand pounds per square inch, but a burn resistance that is slightly lower such as about 7,000 psi. This could be further illustrated in light of Example 3 that includes a high amount of nickel such as about 84 weight percent and about 3 percent titanium and about 1.3 weight percent aluminum. Although the composition also includes about 4 weight percent molybdenum, the composition achieves a tensile strength of about 140 thousand pounds per square inch, while including a combustion resistance of about 10,000 psi. Therefore, even providing various alloys, the tensile strength and the burn resistance can vary greatly. Therefore, the selected compositional ranges of the various alloys and the various elements selected for the alloys may be chosen to achieve various results within selected ranges.

Furthermore, increasing various compositional elements above selected ranges can decrease the selected characteristics. For example, providing a low amount of nickel and a high amount of chromium and molybdenum, such as in Waspaloy®, achieves a high tensile strength but a very low combustion resistance. Other compositions such as Haynes® 214™, that include a high amount of nickel and a high amount of chromium or a low amount of gamma prime formers, such as only 4.5 weight percent aluminum, may achieve high combustion resistance but a low tensile strength. Therefore, it can be seen that the various embodiments achieve a selected characteristic of both a high combustion resistance and a high tensile strength.

The combination of a high tensile strength and a high combustion resistance provides selected alloys that may be used in an unprotected manner for selected applications such as rocket engine components. Various rocket engine components may include items such as pre-burners, turbine disks, turbine housings, ducts, hot gas manifolds and main injector assemblies. These components for rocket engines provide for the high thrust and power achievements in an oxygen rich and high flow environment. These high flow environments achieve very high pressures and forces that must be maintained within strong structural components.

Generally, these structural components are also selected to have a lightweight. Therefore, a high tensile strength of the material from which the components are formed is selected. For example, a lower tensile strength alloy may be used if a thicker wall is used to form the components. This may require more mass and a higher weight for the component.

In addition, the various components are used within a high pressure oxygen environment. This may be so due to the lack of oxygen in various operating environments, such as outside of the atmosphere of the earth, or to ensure a high oxidation concentration with the fuel to form the thrust and power required. Therefore, the components may also be selected to include a substantially high combustion resistance. Therefore, the component generally is selected to include both a high combustion resistance and a high tensile strength. Therefore, the component may both be light and strong and also not degrade, such as under combustion, in a selected use.

Thus, it is selected to include an alloy that has a tensile strength of at least about 145 thousand pounds per square inch and a combustion resistance of at least about 4,000 psi. Although it may be selected to include a higher tensile strength and a higher combustion resistance for various applications, such as about 170 thousand pounds per square inch for tensile strength and about 10,000 psi for combustion resistance. Therefore, such alloys may be used to produce substantially light components while being both strong enough for various applications and achieving a substantially low combustion probability.

The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention. Moreover, the examples included herewith are for illustrative purposes only and not intended to be limiting.

1. A burn resistant, oxidation resistant and high tensile strength alloy, consisting of:
   - 70 to about 75 weight percent nickel;
   - about 10 to about 17 weight percent cobalt;
   - about 6 to about 15 weight percent chromium;
   - about 1 to about 4 weight percent aluminum;
   - about 1 to about 4 weight percent titanium;
   - at least one of carbon, boron, or zirconium;
   - wherein the alloy has a tensile strength of at least about 145,000 pounds per square inch;
   - wherein the alloy is oxidation resistant; and
   - wherein the alloy has an extinguishing threshold pressure of at least about 4,000 pounds per square inch.

2. The alloy of claim 1, wherein the chromium content is about 7 to about 9 weight percent.

3.-29. (canceled)

* * * * *