

TABLE 3

Alloy Properties									
Alloy #	N <sub>R</sub> (%)	N <sub>M</sub> (%)	Hardness (HV <sub>1000</sub> )	YS (MPa)	UTS (MPa)	% elong.	n	CVN (J)	
NSS.057	0.51	0.50	312	602	956	32.30	0.181	25	
NSS.082	0.84	0.97	303	642	1096	55.70	0.214	69	
NSS.083	0.79	0.94	298	635	1089	59.35	0.218	115	
NSS.084	0.81	0.84	293	565	1034	57.85	0.231	126	
NSS.085	0.73	0.86	296	609	1066	57.80	0.221	140	
NSS.086	0.69	0.83	275	591	1066	53.90	0.225	132	
NSS.087	0.77	0.88	300	642	1100	53.10	0.213	129	

N<sub>R</sub> = the protected nitrogen content

N<sub>M</sub> = is the measured nitrogen content

YS = yield strength

UTS = ultimate tensile strength

n = the strength hardening exponent

CVN = Charpy V-notched impact energy

The properties of ultimate tensile strength, yield strength and elongation were measured in accordance with ASTM E8. ASTM E646 was followed to calculate the strain hardening exponent, and ASTM E23 was followed to calculate the impact energy. The measured uncertainty for the ultimate impact strength and yield strength is  $\pm 17$  MPA,  $\pm 1.3\%$  for elongation values,  $\pm 0.003$  for the strain hardening exponent and  $\pm 4$  J for the impact energy.

The volume fraction of the gamma ( $\gamma$ ) phase for all the alloys having the composition described in Table 1 exceeds 0.99, except for NSS.057, a comparative example, which exhibited a volume fraction of gamma ( $\gamma$ ) phase of about 0.67.

FIG. 1a shows the microstructure of NSS.057 which has been subject to a gas atomization and Hot Isostatic Pressing. As can be seen in this micrograph, the alloy exhibits a duplex matrix, and has Cr<sub>2</sub>N and sigma ( $\sigma$ ) phase inclusions. FIG. 1b shows the same alloy which has been further solution treated and quenched. It can be seen that the Cr<sub>2</sub>N and sigma ( $\sigma$ ) phase inclusions have been removed. However, in this alloy both the ferrite and austenite phase remain present in the alloy.

In contrast, FIG. 2 shows the microstructure of consolidated high nitrogen stainless steel of the present invention. In particular, FIG. 2 is a micrograph of the structure for NSS.085. As can be seen, the structure is a fully dense equiaxed grain structure. The micrograph also shows the inclusion of small precipitates of manganese silicate amounting to less than 1% by volume of the structure. This data is typically for the alloys prepared in accordance to this invention.

FIG. 3 shows the typical x-ray diffraction pattern produced by the alloys of the present invention. A relatively narrow scan ( $\Delta 2\theta = 20^\circ$ ) is shown for clarity, however, even in  $2\theta = 100^\circ$  there is no evidence of secondary phases in the stainless steel alloys of the present invention either before or after HIP consolidation.

As can be seen in Table 2, in general, as the nitrogen content is increased, the chemical properties are improved. As the nitrogen mass fraction varies between 0.83 to 0.97, the Vickers hardness varies from 280 HV<sub>1000</sub> to 303 HV<sub>1000</sub>, yield strength varies from 565 MPA to 642 MPA, and the UTS varies from 1034 to 1100 MPA. The microhardness and

the yield strength are plotted against the nitrogen content in FIGS. 4 and 5 respectively. As can be seen in these figures, as the nitrogen content increases, so does the hardness and yield strength of the resulting alloy.

The increased hardness of the alloys of the examples and the high n values are expected to result in an improvement in wear resistance. After a preliminary evaluation using dry pin-on-disk testing, the coefficient of friction for these alloys falls in the range of  $\mu = 0.5$  to 0.6, which is similar to commercial steels.

In addition, the relatively high impact strength of the alloys in a further indication that there is a less likelihood that the alloys have secondary phases. As is known in the art, secondary phases, such as ferrite, stable nitrides and sigma ( $\sigma$ ) phases reduce the impact strength of alloys as compared to alloys without these secondary phases.

Each of the stainless steel alloys prepared in accordance with the foregoing examples was tested for corrosion resistance against an orthopedic implant grade 316L stainless steel. FIG. 6 shows the relative resistance of these alloys to corrosion and were evaluated by conducting an electrochemical polarization experiment. In these experiments, the relative corrosivity of the environment required to cause pitting of the different alloys was quantitatively assessed by increasing the potential of the sample with respect to the reference reaction in a slow and continuous manner until pitting occurred. With this technique, the onset of pitting can be detected and a relatively large increase is incurred and can be then verified with optical microscopy. FIG. 6 is plot of the polarization currents as a function of the potential with respect to an electrochemical reference reaction in a solution, used to evaluate corrosion resistance of alloys for orthopedic implants. As can be seen from FIG. 6, the pitting of the alloys of the present invention do not occur until the potential was 600 mV higher than required to cause pitting of the orthopedic implant grade stainless steel 316L. This means that the alloys of the present invention are significantly more resistant to pitting than 316L and that a significantly higher oxidation potential will be required to cause pitting of the alloys of the present invention as compared to 316L.

The high nitrogen stainless steel alloy of the present invention can be used to prepare articles of manufacture