

MEANS TO IMPROVE MACHINABILITY OF SINTERED STAINLESS STEEL

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ABSTRACT

Austenitic stainless steels are difficult to machine, and if a significant amount of machining is required in an application, one often has no choice but to use a sulfide containing grade, such as 303L, or 316L admixed with MnS. The presence of sulfides in an austenitic stainless steel, however, lowers its corrosion resistance significantly. Addition of a small amount of Sn and Cu has been reported in the literature to significantly improve corrosion resistance of austenitic stainless steels, including that of the sulfide containing grade. Addition of Sn and Cu is also reported to have a favorable influence on the machinability of sulfide free grades of P/M austenitic stainless steels.

This study evaluates the machinability and corrosion resistance of the standard grades, 303L and 304L, along with their Sn and Cu modified versions, 303LSC and 304LSC, and a Cu modified version of 303L, called 303LCu. In this study all sintering was carried out under conditions that are known to be 'optimal' from the corrosion resistance point of view. Machinability was determined by the use of a drilling test.

INTRODUCTION

The P/M process, owing to its near-net shape capability, largely reduces the need for machining. Still, there are some situations where machining is considered a necessity. Typical features of a part that cannot be molded in, and hence must be machined in, are threads, radial holes, under-cuts, and collars. In some other situations machining may be essential for meeting the dimensional tolerances of a part. Consequently, for parts that do require machining, machinability of the sintered material can exert a significant influence on the cost of manufacture, as well as on the surface quality of the finished part.

Corrosion resistance is the primary reason for selecting stainless steel in a given application. The austenitic grades of stainless steel (300 series) offer superior resistance to corrosion, as well as to oxidation, when compared to the ferritic and martensitic grades (400 series) of stainless steel. Austenitic stainless steels also exhibit superior ductility and toughness. Compared to the ferritic and martensitic grades, however, the austenitic stainless steels are more difficult to machine - partly stemming from their inherent tendency to work harden rapidly.

The most popular grades of austenitic stainless steels in P/M, as well as in wrought, are 303L, 304L and 316L. Among these, 316L is considered the premium grade because of its higher alloy content. The 304L is considered the standard austenitic grade, having been derived from the original '18-8' alloy, offering a corrosion resistance that is satisfactory for a wide range of applications. The composition of 303L is similar to that of 304L, except that it is modified by a small addition of sulfur with the purpose of improving its machinability. Sulfur is added to the alloy during melting, which results in the formation of sulfides of Cr and Mn. Present in the matrix as small globules, these sulfides act as chip breakers during machining, and in addition lubricate the tool tip. An alternate approach to improve machinability of a P/M austenitic stainless steel, which is frequently practiced with 316L, is to admix a machinability enhancing agent, such as MnS or MoS₂, with the stainless steel powder prior to compaction. Unfortunately, the presence of sulfides in the alloy matrix, whether admixed or in-situ formed, does lead to a significant loss of corrosion resistance for the alloy [1]. This effect is significant in both the wrought and P/M stainless steels. Since a P/M stainless steel, even when processed very carefully, exhibits a significantly reduced corrosion resistance compared to its wrought counter part, any additional loss in corrosion resistance due to the presence of sulfides can be highly undesirable. As a result, it is difficult to find a grade of P/M stainless steel that is suitable for an application requiring both superior corrosion resistance and superior machinability. Most often, one has to favor one requirement over the other.

It has been known for over two decades that corrosion resistance of a P/M austenitic stainless steel can be enhanced via surface modification, utilizing Sn, Cu, and/or Ni [2, 3, 4]. Addition of small amounts of these elements, either individually or in combination, via the pre-alloying route, has been shown to significantly increase the corrosion resistance of P/M austenitic stainless steels. A family of commercially successful, surface modified, austenitic stainless steels is known as the 'LSC's. The individual alloys of this family are identified as: the 303LSC, the 304LSC, and the 316LSC. These are modified by pre-alloying with nominally 1% Sn and 2% Cu. While the effect of this type of surface modification on the corrosion resistance has been extensively studied and is well documented, very limited amount of information is available in the literature about their effect on machinability. A study published by Kusaka et. al is possibly the only one on this subject [4]. They have found a significant positive effect of pre-alloying austenitic P/M stainless steels with Sn and Cu on their machinability. More recently, some parts makers have also commented that these Sn, Cu modified grades exhibit superior machinability as compared to their standard 'L' grade counterparts. This study was initiated to confirm and quantify the beneficial effects of pre-alloying P/M 303L and 304L with Sn and Cu on their machinability, as well as on their corrosion resistance. Additionally, a Cu modified 303L (303LCu) was also included in the study.

It may be noted here that both corrosion resistance and machinability are significantly influenced by several key process parameters, including sintering atmosphere, sintering temperature and sintered density. Hence, there can be significant variance in the outcomes of studies carried out under different sets of processing conditions. In this study, process parameters that are known to be 'optimal' from the corrosion resistance point of view were employed [5]. Machinability was determined by the use of a drilling test.

MATERIALS

All five grades of austenitic stainless steel powders used in the study were commercial, compacting grade powders, made via water atomization. Table 1 lists their chemical compositions. Additions of the modifiers, Sn and Cu, were made via pre-alloying. The nominal particle size of these powders was minus 100-mesh (<149 micrometers).

All powders were tested for freedom from contamination with less noble metal powders (e.g., iron and ferritic stainless steel powders), by utilizing the Copper Sulfate Test. This was essential in order to ensure

that the results of the corrosion tests are not influenced by the presence of such particulate contaminants in the test material. All powders were lubricated with 1% Kenolube + 0.2% lithium stearate, to aid in compaction.

Table 1: Powder compositions, in weight %

Alloy grade	Cr	Ni	Si	Mn	P	S	Sn	Cu	C	Fe	O
303L	17.7	11.4	0.85	0.10	0.013	0.20	0.0	0.0	0.016	Bal.	0.24
303LSC	17.6	11.9	0.85	0.10	0.012	0.18	0.8	1.99	0.017	Bal.	0.25
303LCu	17.7	12.0	0.85	0.10	0.013	0.21	0.0	2.05	0.018	Bal.	0.24
304L	18.1	11.3	0.85	0.10	0.011	0.006	0.0	0.0	0.016	Bal.	0.24
304LSC	18.2	11.0	0.80	0.13	0.012	0.007	0.8	2.00	0.021	Bal.	0.25

PROCESSING

Three types of specimens were prepared from each of the five powders, as shown below.

1. Round discs having a diameter of 80 mm (3.15 in) and a thickness of 25 mm (1.0 in), for machinability testing.
2. Standard 'dog bone' tensile test specimens with a gage length of 25 mm (1.0 in), for tensile testing.
3. Transverse rupture strength (TRS) specimens measuring 31.75 mm (1.25 in) x 12.7 mm (0.5 in) x 6.35 mm (0.25 in), for determination of compacting properties, sintered properties and corrosion resistance.

Specimens of the above three types were compacted from the five powders, keeping their green densities in the range of 6.44 to 6.46 g/cm³ by utilizing a hydraulic press. Specimens were delubricated in an atmosphere of dissociated ammonia at 550 °C (1022 °F) for 20 minutes. Sintering was carried out in a dry, 100% hydrogen atmosphere at a temperature of 1315 °C (2400 °F), for 30 minutes. The dew point of the sintering atmosphere was – 46 °C (-55 °F). Both delubrication and sintering were conducted in a laboratory scale batch furnace.

TESTING

COMPACTING AND SINTERED PROPERTIES:

The lubricated powders were tested for apparent density and flow rate, green strength, and green density in accordance with MPIF Standards 04, 15 and 45, respectively. Sintered TRS specimens were used for measurement of apparent hardness, dimensional change, sintered density, and transverse rupture strength in accordance with MPIF Standards 43, 44, 42 and 41, respectively. Sintered TRS specimens were also utilized for determination of oxygen, nitrogen, carbon and sulfur analyses. Oxygen and nitrogen contents were determined using a LECO Model TC-436 analyzer, and the carbon and sulfur analyses were made using a LECO Model CS-244 analyzer.

Sintered "dog bone" tensile test specimens were tested using an Instron constant displacement hydraulic test machine for determination of yield strength, tensile strength and percent elongation, as per MPIF Standard 10.

CORROSION RESISTANCE

Sintered transverse rupture strength (TRS) specimens were utilized for corrosion tests. From each of the five grades of material, six replicate specimens were utilized in this test. The test was performed by immersion in a neutral 5% sodium chloride solution, as per ASTM Test Method B 895-99.

Test specimens were placed in individual glass jars (closed top) containing the test solution. A layer of 3 mm (0.1 in) diameter glass beads was placed at the bottom of each jar as sample support, in order to help minimize crevice corrosion. The specimens were periodically examined for evidence of corrosion (stain or rust). The observations were recorded in accordance with the following scale:

<u>Rating</u>	<u>Criteria</u>
“A”	Until any sign of rust or stain
“B”	Up to 1% of specimen surface covered with rust or stain
“C”	Up to 25% of specimen surface covered with rust or stain

The elapsed time, for each specimen, from the beginning of the test until a rating change was determined; and the average values of the ‘A’ and the ‘B’ rating hours for each set of specimens were computed.

MACHINABILITY

A drilling test was employed to determine relative machinability of the five test materials. From each of these materials fifteen test blocks measuring 80 mm in diameter x 25 mm in thickness (3.15 in diameter x 1.0 in. in thickness) were utilized in the test. All drills used in the test were from the same production lot. The test parameters were as follows:

Drill size:	3.5 mm (0.138 in) in diameter
Drill type:	HSS M-2, DORMER A 108 Jobber drill for stainless steel, DIN 388
Drill speed:	700 rpm
Drill force:	789 N (177.5 lbf)
Lubrication:	None
Hole depth:	12 mm (0.5 in)
Spacing:	7.0 mm (0.28 in), center-to-center

A new drill was used for each test, and the test criterion was set as the number of holes drilled until the drill was worn out sufficiently to stop drilling. With each material fifteen tests were performed. There was some scatter in the test results within each material. The mean and the standard deviation of each set of fifteen data points were computed.

RESULTS AND DISCUSSION

COMPACTING AND SINTERED PROPERTIES

Table 2 shows the compacting properties of the five powders. While there were small variations in their apparent density and the -325 mesh content, the compressibility of all five powders fell within a narrow range. This indicates a negligible effect, if any, of pre-alloying with small amounts of Cu, Sn, and S on the compressibility of the standard austenitic alloy 304L. At higher levels of addition, Kusaka et al, have observed a favorable effect of Cu, and an adverse effect of Sn, on compressibility [4]. Similar effects have also been reported by Chatterjee et. al, who have studied such alloy modifications via the admix route [3]. The similarity of the five powders in their apparent density and compressibility is considered an advantage, as it would permit a part maker to easily switch from one grade to another in a given process.

More significant differences are noted in the sintered properties of these materials, which are shown in Table 3. The sintered densities of the three sulfur containing grades are slightly higher than those of the two sulfur free grades. This is also reflected in the higher dimensional changes of the three sulfur containing grades. This effect may be attributed to the formation of a small liquid phase due to the melting of the sulfides during sintering.

Table 2: Properties of lubricated powders

Alloy grade	303L	303LSC	303LCu	304L	304LSC
Apparent density, g/cm ³	3.08	3.06	3.09	2.79	3.08
Flow rate Sec/50g Hall	31.3	33.8	29.2	35.9	34.4
-325 mesh fraction, ($< 45 \mu\text{m}$), weight %	42.5	42.6	48.0	44.9	46.6
Green density, g/cm ³ @ 560 Mpa ($40.6 \times 10^3 \text{ psi}$)	6.44	6.46	6.46	6.45	6.45
Green strength, MPa, (<i>psi</i>) @ 560 Mpa ($40.6 \times 10^3 \text{ psi}$)	7.15 (1037)	7.36 (1067)	9.17 (1330)	9.83 (1425)	7.32 (1061)

Table 3: Sintered properties

Alloy grade	303L	303LSC	303LCu	304L	304LSC
Sintered density, g/cm ³	6.82	6.87	6.88	6.78	6.76
Tensile strength, MPa ($\times 10^3 \text{ psi}$)	325 (47.1)	324 (47.0)	323 (46.8)	338 (49.0)	311 (45.1)
Yield strength MPa ($\times 10^3 \text{ psi}$)	144 (20.9)	157 (22.7)	150 (21.8)	148 (21.6)	152 (22.0)
Elongation, %	25.1	21.5	22.9	26.9	21.8
Hardness, HRB	29	31	28	30	25
Dimensional change % from die size	-2.14	-2.42	-2.34	-1.95	-1.98

Table 4: Oxygen, nitrogen, carbon and sulfur analyses of sintered samples

Alloy grade	303L	303LSC	303LCu	304L	304LSC
Oxygen, ppm	1838	1501	1395	1225	1035
Nitrogen, ppm	108	109	100	102	122
Carbon, wt. %	0.019	0.019	0.020	0.020	0.022
Sulfur, wt. %	0.137	0.084	0.112	0.002	0.002

It is interesting to note that the sulfur contents of all three 303L type materials decreased by nearly 50% during sintering. The significant decrease in the oxygen and nitrogen contents of all materials noted here are typical of high temperature sintering utilizing a dry, 100% hydrogen atmosphere. Oxygen and nitrogen reductions are highly desirable from the corrosion resistance point of view.

MICROSTRUCTURES

Sulfides were present in the matrices of the sintered 303L and its modifications mostly as fine globules, typically measuring 2 to 3 micrometers in diameter (0.00008 to 0.00012 in). Figure 1 and 2 show the typical microstructures of sintered 303L and 304L, respectively. We also observed a small degree of 'pooling' of the molten sulfides in the 303L samples adjacent to some of the pores, as represented in Figure 3. Evidently, the high degree of pore connectivity in these relatively low density samples had a role in their formation.

By working with wrought stainless steels, Kovach and Moskowitz have determined that the type of sulfide that forms in a re-sulfurized stainless steel is determined by the Mn:S ratio in the alloy [6]. At low Mn:S ratios of less than 0.4, only a chromium sulfide forms, which has a hexagonal structure and is brittle. At intermediate Mn:S ratios, ranging from 0.4 to 1.8, a cubic, chromium rich, manganese sulfide forms. At Mn:S ratios of greater than 1.8, pure MnS forms in the matrix. From the corrosion resistance point of view, the pure form of MnS is most undesirable, although it is most beneficial from the machinability point of view. In the current 303L material, and its modifications, the Mn:S ratios are close to 1.0, indicating that the sulfides in these three materials are chromium rich, manganese sulfides rather than pure MnS.

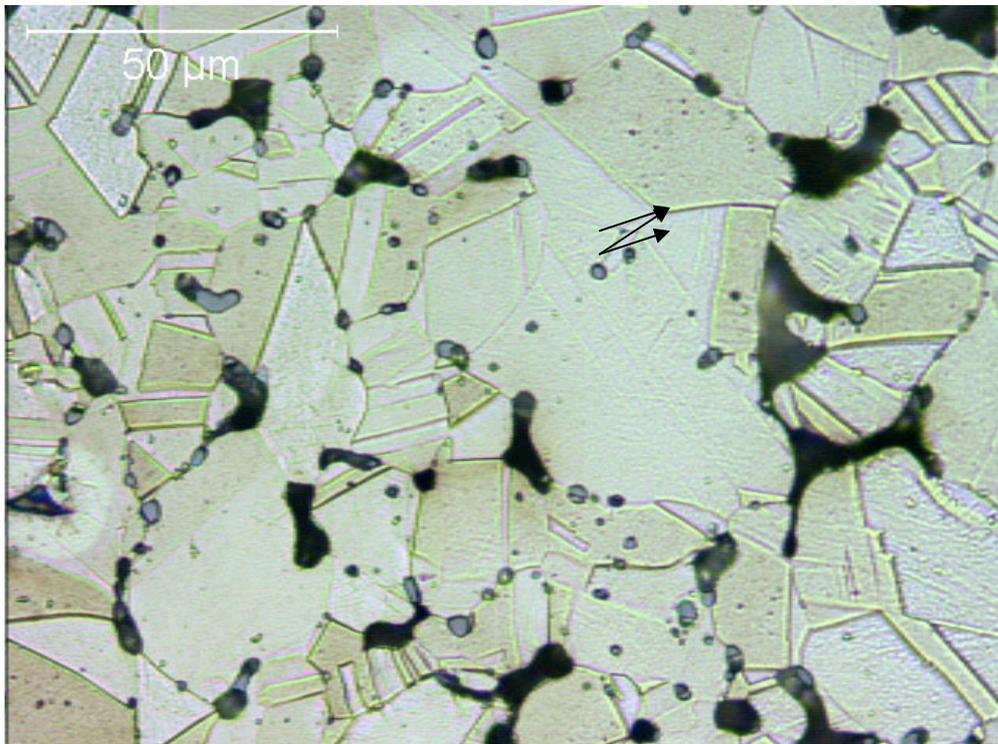


Figure 1: Microstructure of sintered 303L, showing sulfide precipitates. (Glyceregia etch)

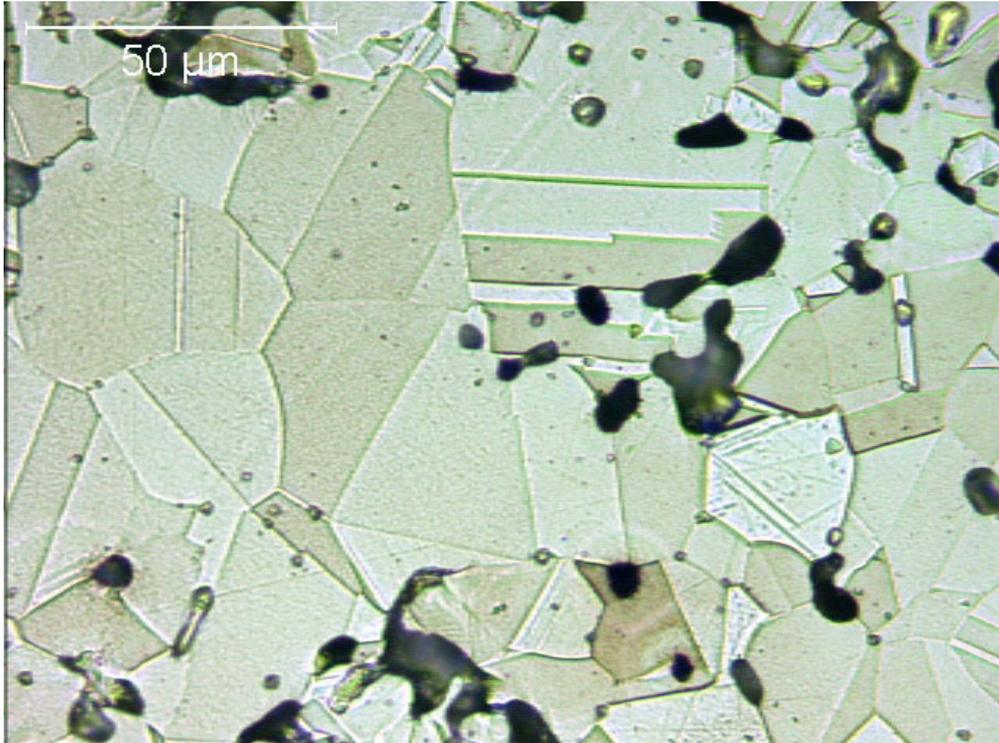


Figure 2: Microstructure of sintered 304L. (Glyceregia etch)

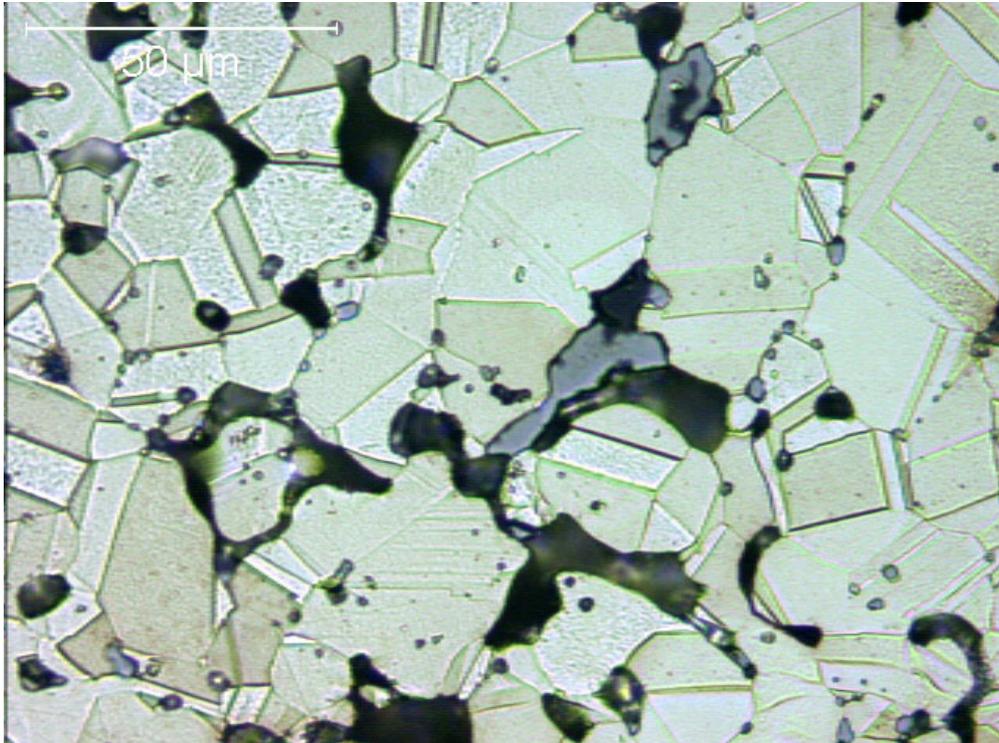


Figure 3: Microstructure of sintered 303L showing large sulfide precipitates, due to 'pooling'. (Glyceregia etch)

As may be noted in Table 3, Sn and Cu additions have a small adverse effect on ductility, in the cases of both 303L and 304L. This is also reflected in a corresponding increase in their yield strengths. Kusaka et. al have observed a similar effect in their study, and have attributed this to the formation of a fine precipitate in the matrix. The microstructure of 303LSC and 304LSC, in the un-etched condition, show the presence in the matrix of some very fine precipitates measuring typically 0.5 micrometers (0.00002 in.) in diameter, having a reddish color (Figure 4). Kusaka et. al have carefully analyzed these reddish precipitates, and have concluded that these precipitates are mainly composed of the Ni(Cu)Sn eutectic constituents, which have a melting point below 1200 °C (2192 °F) [4].

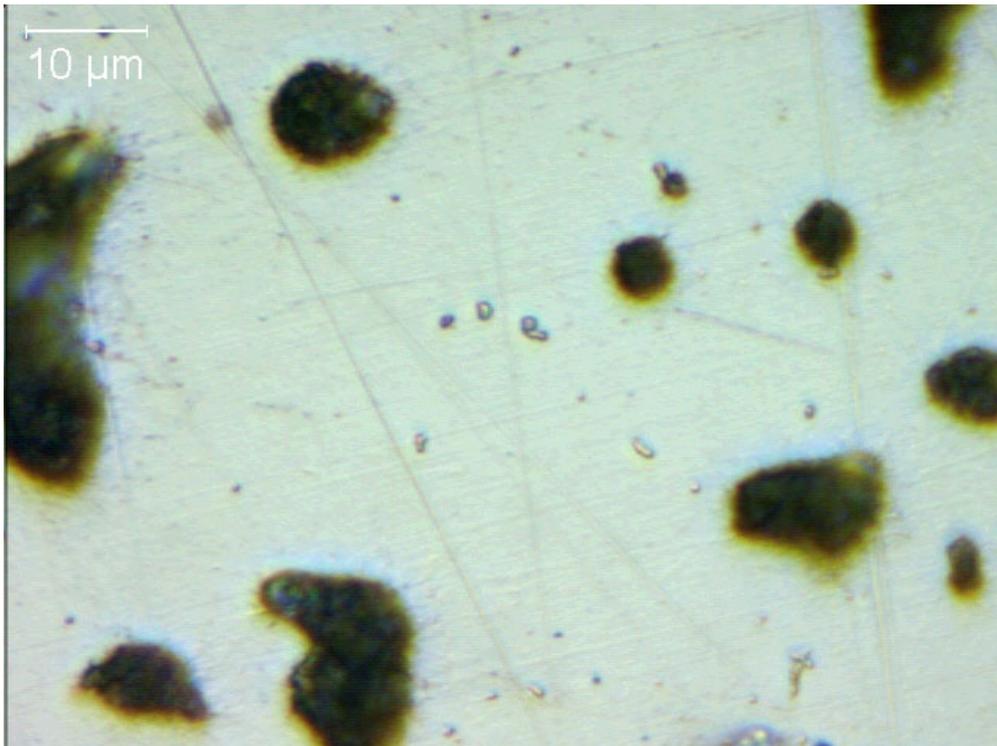


Figure 4: As-polished surface of sintered 304LSC showing fine precipitates of the Ni(Cu)Sn eutectic constituents.

CORROSION RESISTANCE

Corrosion resistances of the five materials are listed in Table 5. Corrosion resistances of 303L, 303LSC, 304L and 304LSC observed here are similar to those of most published data [7, 8]. Typically, the 'B' rating hours for the 'optimally' sintered 303L and 304L are 50 and 100, respectively: and those for the 'optimally' sintered 303LSC and 304 LSC are 600 and 1000, respectively. Alloy 303LCu is a relatively new material and data on its corrosion resistance are limited.

In the literature, the mechanism behind the beneficial effect of Sn modification has been better explained than it is for Cu modification. Utilizing Auger and ESCA analyses, Ro and Klar have determined that in the LSC's, Sn is enriched on the surface of the water atomized powder, as well as on the surface of the sintered part [8]. The Sn-rich layer is considered to be more or less a continuous one; and unlike the SiO₂ layer, which also is present on the surface of the water atomized powder, it remains un-damaged during powder compaction. This Sn-rich layer is chemically more stable, possessing the ability to withstand a higher level of acidity than the Sn-free stainless steel surface. Thus, the Sn-rich layer provides for a chemically more stable passive layer on the surface of the part, including the surfaces within the pores.

In the absence of extraneous factors (e.g., oxides, carbides and nitrides), corrosion of a P/M stainless steel is promoted by the classical crevice corrosion phenomenon, and it is governed by the progress of the acidity of the stagnant media in the crevice. The presence of a chemically more stable passive film, owing to Sn, delays the onset of crevice corrosion.

By conducting potentiodynamic tests on sintered stainless steels in 3.5% sodium chloride medium Lei and German have determined that the Sn, Cu modified, 304LSC does exhibit significantly lower corrosion current in the passive range, compared to standard 304L alloy [9]. This effect was not seen by them, in alloys modified by Sn only, or with those modified by admixing Sn and Cu.

Although the Kusaka et. al study was less extensive in its evaluation of the corrosion behavior, they also concluded that the Sn, Cu modification delayed the onset of corrosion in an electro-chemical way.

A secondary benefit from Sn, Cu modification is realized in the form of a greater ‘forgiveness’ of these alloys to marginal sintering atmospheres and cooling rates. The Sn-rich surface hinders absorption of nitrogen during sintering and cooling in a nitrogen-bearing atmosphere. This reduces the tendency of the chromium based alloy to form deleterious chromium nitrides on the surface in a ‘marginal’ sintering operation. Similarly, the Sn-rich surface helps retard re-oxidation of the surface of a sintered part during sintering and/or cooling in a ‘marginal’ dew point atmosphere.

Table 5: Results of the corrosion tests

Alloy grade	303L	303LSC	303LCu	304L	304LSC
“A” Rating hours	24	372	210	58	620
“B” rating hours	54	756	452	112	1284

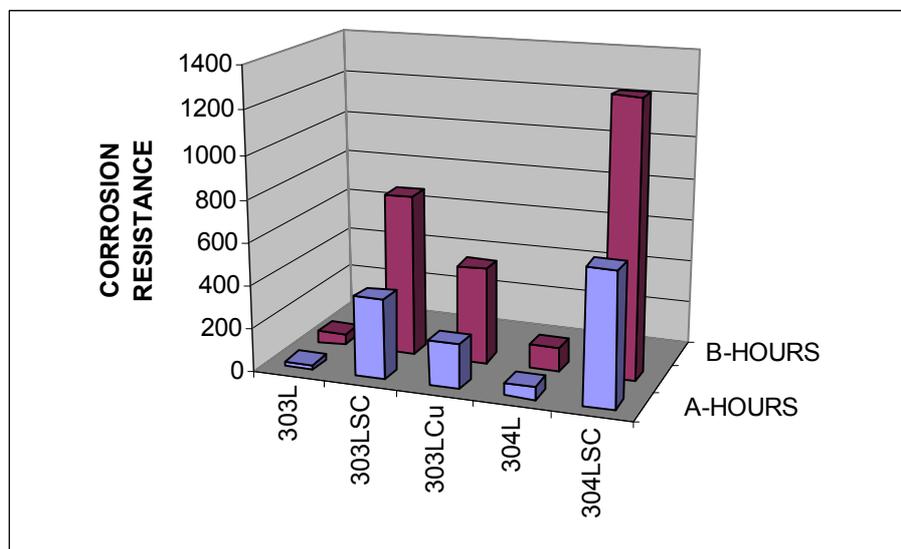


Figure 6: Corrosion resistances of the five materials, expressed as “A’ rating hours, and “B” rating hours

The significantly lower corrosion resistance of 303L, relative to that of 304L, determined here may be entirely attributed to the presence of sulfides in 303L. As discussed earlier, the sulfides present in 303L are considered to be chromium rich MnS, rather than pure MnS. Kusaka et. al, have suggested that the

reduced corrosion resistance of 303L may be attributed to chromium depletion on the surface of the part that results from the formation of the chromium rich MnS [4]. This effect is different from what occurs when pure MnS is present in the material. In the latter case, the less noble MnS leads to formation of galvanic couples, which leads to a more drastic loss of corrosion resistance. Samal and Terrell, in a study based on admixing various amounts of MnS to 316L, found that with as little as 0.3 % MnS addition the corrosion resistance of 316L was reduced from 1657 ‘B’ rating hours to 7 ‘B’ rating hours [1].

The current study shows that with 303L, both Sn, Cu modification, and the Cu modification go beyond simply restoring the corrosion resistance to the level of the standard 304L alloy, and do lead to significantly enhanced corrosion resistance. In the case of the Sn, Cu modification at least, it appears that the surface enrichment that leads to a chemically more stable passive layer in the pores, substantially overcomes the localized chromium deficiency caused by the formation of sulfides.

The sintered densities of all samples fall within the density range that is known to promote crevice corrosion (87 to 90% of theoretical full density) [10]. As a result, it was not surprising to find crevice corrosion to be the most prevalent mode of corrosion in these samples. It is likely that at sintered densities out side of this range all five materials would exhibit somewhat higher corrosion resistance, with the 303L and 304L most likely showing the highest improvement.

MACHINABILITY

Table 6 lists the results of the machinability (drilling) test. As expected, alloy 304L shows the lowest machinability. This represents the typical degree of difficulty encountered while machining a standard austenitic stainless steel. Alloy 303L exhibits a ten-fold increase in machinability due the presence of approximately 0.1 wt. % sulfur. Although, the machinability of 303L would likely increase with increasing sulfide content, it probably will be undesirable from the corrosion resistance point of view. Kusaka et al. had noted 0.2% sulfur content to be the optimum for reduction of cutting force [4].

Both 303L and 304L benefit from Sn, Cu modification in terms of machinability. In case of 304L the improvement is significant, given the extremely low machinability of the standard alloy. The benefit achieved in the case of 303L from Sn, Cu modification is a relatively modest one. Overall, these results indicate that the Sn, Cu modification does lead to an improvement in machinability. As suggested by Kusaka, et al., the mechanism behind this phenomenon is related to the presence of Ni(Cu)Sn precipitates in the matrix discussed above [4].

Table 6: Results of the machinability test

Alloy grade	303L	303LSC	303LCu	304L	304LSC
Individual test results, (number of holes drilled prior to drill failure)	44, 27, 21, 7, 23, 35, 21, 18, 26, 20, 28, 26, 14, 19, 7	29, 22, 25, 39, 33, 28, 16, 22, 35, 23, 25, 28, 26, 15, 25	39, 19, 27, 29, 37, 28, 36, 28, 28, 39, 32, 45, 47, 23, 15	2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2	5, 7, 7, 4, 5, 6, 6, 6, 4, 5, 6, 6, 7, 6, 6
Mean (number of holes)	22.4	26.1	31.5	2.0	5.7
Standard deviation	9.6	6.4	9.0	0	0.96

Modification of 303L with Cu leads to a greater improvement in machinability, than what is achieved from Sn, Cu modification. Here, a 50% improvement is noted over 303L. It is speculated that the Cu present in the material provides lubrication for the tool tip.

With both 303L and 303LCu, greater variations are noted in their machinability data. The standard deviations of these two data groups are fairly high. This is attributed to the tendency of the liquid sulfides to form as ‘pools’, resulting in a somewhat non-uniform distribution of the machining aid in the material.

As seen in Figure 7, these five materials combine a wide range of corrosion resistance and machinability, thereby offering the P/M parts maker a good number of choices to help meet the needs of an application.

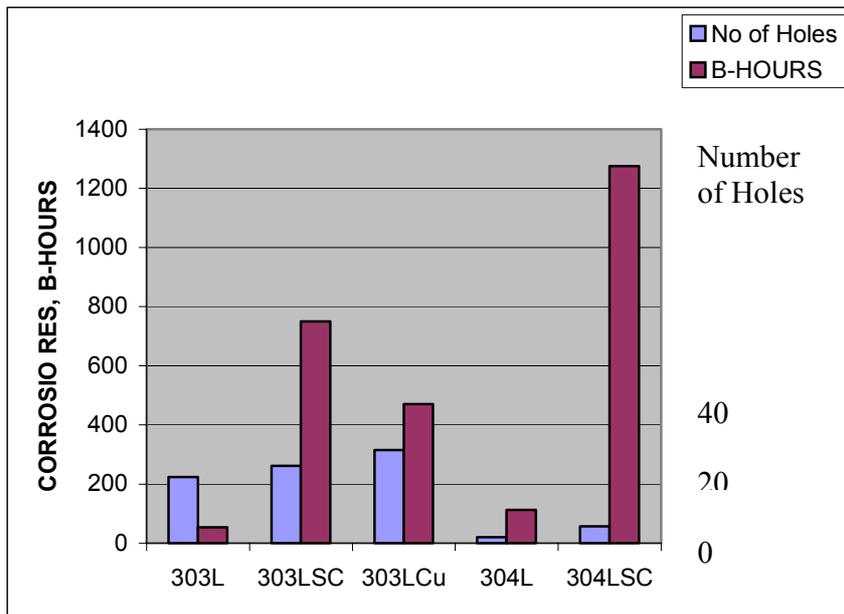


Figure 7: Relative corrosion resistance and machinability of the five materials

CONCLUSIONS

Surface modification of 303L and 304L, with small amounts of Sn and Cu, or only Cu, provides significant benefits in terms of both corrosion resistance and machinability. The detrimental effect from alloying with sulfur can be more than compensated by this approach. Surface modification can be employed to combine a wide range of corrosion resistance and machinability in an austenitic stainless steel.

The standard P/M alloy 303L, even when processed ‘optimally’ has a remarkably low corrosion resistance. Hence, it is highly desirable to enhance its corrosion resistance via surface modification.

Comparing the corrosion resistance and machinability of the five materials, we find that it is easier to improve the corrosion resistance of 303L (via surface modification), than to improve the machinability of 304L. Nevertheless, if an application requires the highest possible corrosion resistance, 304LSC may be the material of choice. Alternately, if corrosion resistance and machinability are deemed equally important, then both 303LSC and 303LCu may be considered as the prime candidates.

ACKNOWLEDGEMENTS

The authors would like to thank Jorgen Knuth-Nielsen and Birgit Johansson for assistance with the experimental portions of the study, and the managements of Hoganas AB, and North American Hoganas for permission to publish this work.

REFERENCES

1. P. K. Samal and J. B. Terrell, "Effects of Various Machinability Additives on the Corrosion Resistance of P/M 316L Stainless Steel", *Advances in Powder Metallurgy & Particulate Materials*, vol. 3, compiled by C. L. Rose and M. H. Thibodeau, Metal Powder Industries Federation, Princeton, NJ, 1999, part 9, pp. 15 - 28.
2. M. A. Pao and E. Klar, "On the Corrosion Resistance of P/M Austenitic Stainless Steels", *Proceedings of the International Powder Metallurgy Conference (PM-82 in Europe)* June 20 – 25, 1982, Florence, Italy. Associazione Italiano di Metallurgia, pp. 359 – 374.
3. S. K. Chatterjee, M. E. Warwick, and D. J. Maykuth, "The Effect of Tin, Copper, Nickel, and Molybdenum on the Mechanical Properties and Corrosion Resistance of Sintered Stainless Steel (AISI 304L)", *Modern Developments in Powder Metallurgy*, vol. 16, E. N. Aqua and C. I. Whitman, Editors, Metal Powder Industries Federation, 1984, pp. 277 - 293
4. K. Kusaka, T. Kato, and T. Hisada, Influence of S, Cu, and Sn additions on the Properties of AISI 304L Type Sintered Stainless Steel, *Modern Developments in Powder Metallurgy*, Vol. 16, E. N. Aqua and C. I. Whitman, Editors, Metal Powder Industries Federation, 1984, pp. 247 - 259.
5. E. Klar and P. K. Samal, Production Sintering Practices, *Powder Metal Technologies and Applications*, Metals Handbook, vol. 7, ASM International, Materials Park, Ohio 1998 pp. 474 – 482.
6. C. W. Kovach and A. Moskowitz, "How to Upgrade Free-Machining Properties", *Metals Progress*, vol. 91, ASM International, Materials Park, Ohio August 1967, pp. 173-180.
7. E. Klar and P. K. Samal, Powder Metallurgy Stainless Steels, *Powder Metal Technologies and Applications*, Metals Handbook, vol. 7, ASM International, Materials Park, Ohio 1998 pp. 774 – 785.
8. D. Ro and E. Klar, *Corrosive Behavior of P/M Austenitic Stainless Steels*, *Modern Developments in Powder Metallurgy*, vol. 13, H. H. Hausner, H. W. Antes and G. D. Smith, Editors; Metal Powder Industries Federation, Princeton, NJ, 1981, pp. 247 - 287
9. G. Lei, and R. M. German, *Corrosion Control in Sintered Austenitic Stainless Steels*, *Progress in Powder Metallurgy*, vol. 39, Metal Powder Industries Federation, Princeton, NJ, 1980, pp. 261 – 275.
10. T. Mathiesen and E. Maahn, *Effect of Pore Morphology on the Corrosion Behavior of Sintered 316L Stainless Steel*, *Advances in Powder Metallurgy & Particulate Materials*, vol. 3, Metal Powder Industries Federation, Princeton, NJ, 1995.