

Nickel release from stainless steels

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In 1994, a study of nickel release and allergic contact dermatitis from nickel-plated metals and stainless steels was published in this journal. It was shown that low-sulfur stainless steel grades like AISI 304, 316L or 430 ($S \leq 0.007\%$) release less than $0.03 \mu\text{g}/\text{cm}^2/\text{week}$ of nickel in acid artificial sweat and elicit no reactions in patients already sensitized to nickel. In contrast, nickel-plated samples release around $100 \mu\text{g}/\text{cm}^2/\text{week}$ of Ni and high-sulfur stainless steel (AISI 303 – $S \approx 0.3\%$) releases about $1.5 \mu\text{g}/\text{cm}^2/\text{week}$ in this acid artificial sweat. Applied on patients sensitized to nickel, these metals elicit positive reactions in 96% and 14%, respectively, of the patients. The main conclusion was that low-sulfur stainless steels like AISI 304, 316L or 430, even when containing Ni, should not elicit nickel contact dermatitis, while metals having a mean corrosion resistance like a high-sulfur stainless steel (AISI 303) or nickel-plated steel should be avoided. The determining characteristic was in fact the corrosion resistance in chloride media, which, for stainless steels, is connected, among other factors, to the sulfur content. Thus, a question remained concerning the grades with an intermediate sulfur content, around 0.03%, which were not studied. They are the object of the study presented in this paper. 3 tests were performed: leaching experiments, dimethylglyoxime and HNO_3 spot tests, and clinical patch tests; however, only stainless steels were tested: a low-sulfur AISI 304 and AISI 303 as references and 3 grades with a sulfur content around 0.03%: AISI 304L, AISI 304L added with Ca, AISI 304L+Cu. Leaching experiments showed that the 4 non-resulfurized grades released less than $0.5 \mu\text{g}/\text{cm}^2/\text{week}$ in acid sweat while the resulfurized AISI 303 released around or more than $0.5 \mu\text{g}/\text{cm}^2/\text{week}$. This is explained by the poorer corrosion resistance of the resulfurized grade. Yet all these grades had the same reaction to the DMG test (negative result), which shows again its lack of sensitivity. In contrast, the HNO_3 spot test distinguished AISI 303 from the non-resulfurized grades. Clinical patch tests again showed that some patients (4%) were intolerant to AISI 303, while none were intolerant to the other grades. Thus, this study confirms that non-resulfurized stainless steels ($S \leq 0.03\%$) like Ni-containing 304 and 304L should not elicit Ni contact dermatitis, while the resulfurized grades ($S > 0.1\%$) should be avoided.

Key words: allergic contact dermatitis; leaching experiments; nickel; stainless steels; prevention; nitric acid spot test; dimethylglyoxime test; elicitation studies. © Munksgaard, 1997.

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The following experiments were carried out: comparative determination of Ni release from these stainless steels in artificial sweat of neutral or acid pH (6.6 and 4.5), and evaluation of this release, a rate less than $0.5 \mu\text{g}/\text{cm}^2/\text{week}$ being considered as safe by Menné (2); dimethylglyoxime (DMG) and HNO_3 spot test; clinical patch testing with metallic samples of the 5 stainless steel grades to evaluate their skin tolerance.

Experiments were conducted at the Ugine Research Centre except for the patch tests, which were performed at the Clinic of Dermatology, Edouard Herriot Hospital in Lyon.

Materials and Methods

Studied materials

In this study, only stainless steel grades were tested. 2 of them had already been tested previously and were used again as references: they are the low-sulfur AISI 304/1.401 ($S = 0.007\%$) as negative reference and the high-sulfur AISI 303/1.4305 ($S = 0.27\%$) as positive reference. The 3 other grades are type AISI 304L stainless steels with an intermediate sulfur content ($S \approx 0.03\%$), 1 of them also supplemented being with Ca (1.4307) and other 1 with Ca and Cu (1.4567) in order to improve ma-

chinability. Their chemical analyses are given in Table 1. These grades will be referred to using the AISI (American Iron And Steel Institute) standard.

For the various AISI 304 and 304L, stainless steels, experiments were performed on polished surfaces (SiC paper). For AISI 303 only the patch tests have been performed again, but this time with polished samples (SiC paper) instead of with samples as received (machined rods), as in the previous study. For the 3 other tests, former results were taken into account, considering that the as-machined samples have a worst surface condition, and thus a worst corrosion resistance, than the polished samples. Prior to experiments, samples were cleaned ultrasonically in a solution of acetone+ethanol (50/50 in volume ratio).

Leaching experiments

These were run in artificial sweat solutions at pH 4.5 or 6.6 at ambient temperature, except for the low-sulfur AISI 304 which was here not tested in neutral sweat. Composition of the artificial sweat solution was as follows: NaCl 0.3%, Na₂SO₄ 0.1%, urea 0.2% and lactic acid 0.2% (1).

Each grade was tested 3× to evaluate reproducibility. Samples were immersed for 1 week in 100 ml of the naturally aerated solution. They were then removed from the solution and rinsed with 50 ml of distilled water acidified with nitric acid (5% in weight). The test solution added with the rinsing water was then analysed using atomic absorption spectrometry (AAS) (detection limit=10 µg/l) to determine the nickel content.

For each set of tests, a blank solution was prepared and analysed by AAS in the same conditions as the test solutions. The nickel-release level for each sample in each solution was thus calculated, having deduced the Ni content of the blank solution.

The mid-sulfur AISI 304 was also tested according to a test proposed by CEN – TC 283 – W.G.4 (prEN 1811) as a standardized test for the European directive 76/769/EEC. The solution was thermostated at 30°C and the composition of the sweat was the following: NaCl 0.5%, urea 0.1%, lactic

0.1% and NH₃ to adjust the pH, which must be equal to 6.5. This test is more aggressive than out test in neutral sweat but might be less severe than our test in acid sweat.

Area of specimens exposed to the above solutions were as follows: AISI 303: 7.07 cm² (pH=4.5) or 10.3 cm² (pH=6.6); AISI 304: 72 cm², AISI 304L without and with Ca: 16.8 cm² and AISI 304L+Cu: 11.3 cm².

Dimethylglyoxime (DMG) and HNO₃ spot tests

As previously, this test was performed to verify its sensitivity and validity. The usual conditions were applied (1). We also applied the HNO₃ test that we proposed previously (1) and which differentiates high-sulfur-containing stainless steels (like AISI 303) from others.

Patch tests

The test was performed on 51 patients already known to be sensitive to nickel (nickel sulfate 5% solution). Circular samples of the 5 SS grades, in the received condition, nickel sulfate 5%, and distilled water as the negative test, were applied on the scapular part of the back with Finn Chambers on Scanpor tape. The patch tests were removed after 2 days, and reading performed 30 min after. Patients were examined again 1 day later. Measurement of the pH of the sweat was performed, with a special flat pH-meter electrode, on the back of the patient.

Results

Leaching experiments

Results obtained for the tests ran in artificial sweat solutions are shown on Fig. 1. The value presented each time is the mean value for the 3 samples. When the Ni quantity released is below the detection limit of the experiments DL is noted. DL corresponds to 0.09 µg/cm²/week.

(i) From these results, 3 main comments can be made:

From the Ni values measures here for AISI 304L+Ca, we cannot say if the releasing test pro-

Table 1. Chemical composition (wg %) of the stainless steel grades and of the nickel used in our study

Grade	Cr	Ni	Mo	S	Ca	C	Mn	Si
AISI 304 1.4301	18.2	8.65	0.26	0.007	/	0.036	0.82	0.49
AISI 304L 1.4301	18.0	9.28	0.35	0.0235	/	0.018	1.09	0.46
AISI 304L+Ca 1.4301	18.3	9.14	0.25	0.0259	0.0043	0.021	1.13	0.61
AISI 304L Cu 1.4567	17.2	9.12	0.34	0.0263	0.0064	0.012	0.84	0.36
AISI 303 1.4305	17.3	8.45	0.26	0.275	0.0055	0.064	1.79	0.54

posed as a standardized one by CEN/TC 283/WG4 is more or less severe than our test in acid sweat since they were all below the DL. Hence, analysis of Cr released during the experiments was also done to compare the 3 tests. Results in $\mu\text{g}/\text{cm}^2/\text{week}$ were the following, respectively, for pH 4.5, 6.5 (CEN test) and 6.6: $\text{Cr}=0.49\pm0.35$, 0.16 ± 0.07 , 0.033 ± 0.04 . This shows that the test with acid sweat is more severe than the standardized test, due to the higher acidity and despite the lower chloride concentration and the lower temperature (these 3 parameters are determining for the corrosivity of the sweat). Thus results obtained in acid sweat can safely be taken into account for comparison with the $0.5 \mu\text{g}/\text{cm}^2/\text{week}$ sensitization limit, in order to determine whether the material will possibly elicit contact dermatitis on already sensitized persons or not.

(ii) In acid sweat, only the high-sulfur stainless steel, AISI 303, had a Ni release level higher than $0.5 \mu\text{g}/\text{cm}^2/\text{week}$, though not much. Other grades tested always exhibited a nickel-release level lower than $0.5 \mu\text{g}/\text{cm}^2/\text{week}$ and, in particular, the 3 mid-sulfur AISI 304. Thus these grades should not elicit positive reactions on Ni-sensitized patients.

(iii) The low-sulfur AISI 304 released more nickel than AISI 304L+Ca: this is surprising since, according to their respective sulfur content, AISI 304 has a higher corrosion resistance than AISI 304L, as we have seen during polarization experiments run during this study but not presented in this paper. In fact, the higher Ni release for AISI 304 might simply be connected to the reproducibility problems frequently encountered with this kind of releasing test.

Dimethylglyoxime (DMG) and HNO_3 spot tests

Results of the spot tests are summarized in Table 2. Again, we can see that the DMG does not differentiate between the stainless steel grades: it gives a negative result for each grade. Thus, according to

Table 2. Results of the DMG and HNO_3 tests

Grade	surface condition	DMG		
		NH_3+ DMG	$\text{HCl}+\text{NH}_3+$ DMG+ H_2O_2	HNO_3
AISI 304	p. 180	<0	<0	<0
AISI 304	p. 180	<0	<0	<0
AISI 304+Ca	p. 180	<0	<0	<0
AISI 304 Cu	p. 1200	<0	<0	<0
AISI 303	as machined	<0	<0	>0

this test, none of these grades should elicit nickel contact dermatitis on Ni-sensitized patients. The results of the HNO_3 test are different, since AISI 303 reacts positively while the non-resulfurized grades react negatively.

Patch tests

The result of the patch tests and pH measurement are presented in Table 3. 1 patient had a major allergic reaction to the nickel sulfate 5% solution, with an eczematous eruption of the whole test area that made the reading ininterpretable. The 5 SS grades were retested separately, one after the other and a slight positive reaction, interpreted as an irritant reaction, was noted for the low-sulfur AISI 304.

96% of the patients had a positive reaction to nickel sulfate 5% solution and 4% to the resulfurized austenitic stainless steel (AISI 303). Slight erythema were observed on 1 patient with the AISI 304L patch test. 2 with the AISI 304L+Ca, and 1 with AISI 304L+Cu, but they were only irritant reactions. Thus, none of the 51 patients showed an intolerance reaction to the 4 non-resulfurized grades.

pH measurements of the sweat on the back ranged from 2.1 to 6.9 (average 5.33 ± 1.28). 6 patients had very acid sweat (between 2 and 3.3), but the average did not differ significantly from the general population.

Discussion

In a previous study (1), we examined the behaviour of various stainless steel grades regarding Ni contact dermatitis. The main conclusions of this work were that: non-resulfurized stainless steels with a sulfur content around 0.003% can be used without any problem in prolonged contact with the skin; resulfurized grades ($S>0.1\%$), like AISI 303, elicit Ni dermatitis in a small % of Ni-sensitized patients after prolonged contact; for stainless steel grades, the sulfur content is a determining parameter that affects corrosion resistance and thus release of Ni. A question that arose from our previous work was

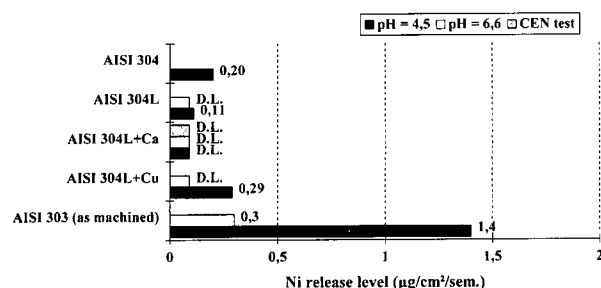


Fig. 1. Amounts of Ni released from various stainless steel after a 1-week immersion in artificial sweat solutions (DL=detection limit= $0.90 \mu\text{g}/\text{cm}^2/\text{week}$).

Table 3. Results of the patch tests and pH measurements performed on 51 patients already sensitive to nickel

Sex	Age (years)	Ni	AISI 304	AISI 304L	AISI 304L+Ca-	AISI 304L+Cu	AISI 303	pH
F	31	++	-	-	-	-	-	6.2
M	29	++	-	-	-	-	-	5.5
F	24	++	-	-	-	-	-	5.4
M	29	-	-	-	-	-	-	4.2
M	22	++	-	-	-	-	++	2.36
F	35	++	-	-	-	-	-	6.0
F	35	++	-	-	-	-	-	5.5
F	37	+	-	-	-	-	-	6.0
F	40	++	-	-	-	-	-	6.3
F	18	++	-	-	-	-	-	5.92
F	24	++	-	-	-	-	-	5.6
F	22	++	-	-	-	-	-	6.3
F	65	+	-	-	-	-	-	6.9
F	50	+	irritant reaction	-	-	-	-	4.5
F	39	++	-	-	-	-	-	6.6
F	64	++	-	-	-	-	-	5.3
F	26	++	-	-	-	-	-	6.0
F	31	++	-	-	-	-	-	5.3
F	33	++	-	-	-	-	-	6.5
F	44	++	-	-	-	-	-	5.8
M	74	++	-	-	-	-	-	6.4
F	45	++	-	-	-	-	-	3.1
F	35	++	-	-	-	-	-	2.9
F	39	++	-	-	-	-	-	6.1
F	38	++	-	-	-	-	-	2.0
F	49	-	-	-	-	-	-	6.8
F	48	+	-	-	-	-	-	6.0
F	32	++	-	-	-	-	-	6.5
F	25	++	-	-	-	-	-	6.5
F	32	++	-	-	-	-	-	6.5
F	36	++	-	-	-	-	-	6.6
F	22	++	-	-	-	-	-	6.5
F	19	++	-	-	-	-	-	6.0
F	24	++	-	-	-	-	-	4.5
F	47	++	-	-	-	-	-	5.5
M	47	++	irritant reaction	-	-	-	-	2.2
F	26	+++	-	-	-	-	-	3.3
F	22	++	-	-	irritant reaction	-	-	5.35
F	38	++	-	-	irritant reaction	irritant reaction	-	5.4
F	47	++	-	-	-	-	-	6.2
F	26	++	-	-	-	-	-	5.0
M	37	++	-	-	-	-	++	5.4
F	27	++	-	-	-	-	-	6.05
F	29	++	-	-	-	-	-	5.3
F	40	++	-	-	-	-	-	4.9
F	35	++	-	-	-	-	-	2.75
F	27	++	-	-	-	-	-	5.65
F	29	++	-	-	-	-	-	3.1
F	22	++	-	-	-	-	-	5.6
F	68	++	-	-	-	-	-	5.6
F	36	++	-	-	-	-	-	5.8

how stainless steel grades containing intermediate levels of sulfur, i.e., around 0.03%, would behave.

Hence, this 2nd study for which we selected 3 Ni-containing grades with a mid-sulfur content ($S \approx 0.03\%$): a standard AISI 304L and 2 AISI 304L supplemented with Ca or Ca+Cu to improve machinability. AISI 316L, which is used for watch-making, was not studied here because in clinical patch testing, we try to test a limited number of

materials and because it is well-known that AISI 316L is more resistant to corrosion and thus releases less Ni than AISI 304L or AISI 304 (1).

In the present study, we show, as in the former one, the following.

The mid-sulfur stainless steel grades release Ni in small quantities (less than $0.5 \mu\text{g}/\text{cm}^2/\text{week}$), just as well in acid synthetic sweat as in neutral. In this case, this is true for a polished surface, which is

not the best surface condition. With finer polishing (electropolishing, mirror polishing...), corrosion resistance would be improved and thus Ni-release would be lower. It would also be lower for industrial surface conditions like bright-annealed surface or pickled and skin-passed surfaces (1).

With the currently proposed CEN test, these grades should also release less than $0.5 \mu\text{g}/\text{cm}^2/\text{week}$, since this test appears to be less corrosive than our test in acid synthetic sweat.

All the grades tested are satisfactory according to the DMG test, while according to the HNO_3 test, the low and mid-sulfur grades are acceptable but not resulfurized grade. This shows that for stainless steels the HNO_3 test is more appropriate than the DMG test, since it can distinguish grades that release Ni in a quantity equal to or more than $0.5 \mu\text{g}/\text{cm}^2/\text{week}$ and which elicit Ni dermatitis in some Ni-sensitized patients, from grades that release less than $0.5 \mu\text{g}/\text{cm}^2/\text{week}$ and elicit no Ni dermatitis in Ni-sensitized patients.

No Ni-sensitized patients had a positive patch test with low or mid sulfur stainless steel grades, while 4% of them showed a Ni dermatitis with AISI 303. This % is lower than in the previous study, which could be explained by a finer surface condition, which implies a higher corrosion resistance, though it could also be due to a different group of patients being tested.

Results of the clinical patch tests have been analysed statistically, using a binomial law, which seems the more appropriate, given the size of the population tested (3). For AISI 303, we took into account the previous results to get a finer analysis. For this grade, we think that it is not incorrect to put together all the clinical results, because in both cases, sample surfaces were polished and thus were not so different from one another. Moreover, the single error that could ensue from this would be to worsen the results for AISI 303, since former results were less good than those of the present study.

Thus, for an infinite Ni-sensitized population and with a confidence level of 95%, we obtain the following results: with non-resulfurized stainless steel grades, less than 7% of the Ni-sensitized population should show Ni contact dermatitis, and there *does exist* a strong probability that none of them would react positively as in our experiment. In contact AISI 303, between 4% and 17%

of this population *will* show such dermatitis on prolonged contact with skin. For Ni-plated metals, it would be between 87% and 99% of the Ni-sensitized population. This means that for resulfurized stainless steels, at least 4% of Ni-sensitized patients would react, which for us is not acceptable. Hence, we recommend not using high-sulfur stainless steels in contact with the skin, but only non-resulfurized grades.

Conclusions

This complementary study on the behaviour of mid-sulfur stainless steels ($S < 0.01\%$) regarding the issue of Ni contact dermatitis has shown that these grades, like low-sulfur stainless steels, can safely be used in prolonged contact with the skin: they release less than $0.5 \mu\text{g}/\text{cm}^2/\text{week}$ of nickel in synthetic sweats, they are satisfactory according to the DMG and HNO_3 tests, and above all they elicit no Ni dermatitis in the 50 already Ni-sensitive patients tested.

We also confirm that resulfurized stainless steels that release around or more than $0.5 \mu\text{g}/\text{cm}^2/\text{week}$ in synthetic sweats, and are unsatisfactory according to the HNO_3 test, elicit Ni dermatitis in some of the Ni-sensitized patients. For an infinite population of Ni-sensitized patients, this means that this grade should elicit Ni dermatitis in at least 4% of this population. Thus, even if the risk is far lower than that which is encountered with Ni-plated metals, we recommend not using such grades in contact with the skin.

References

1. Haudrechy P, Foussereau J, Mantout B, Baroux B. Nickel release from nickel-plated metals and stainless steels. *Contact Dermatitis* 1994; 31: 249-255.
2. Menné T, Brandrup F, Thestrup-Pedersen K, Veien N K, Andersen J R, Yding F, Valeur G. Patch test reactivity to nickel alloys. *Contact Dermatitis* 1987; 16: 255-259.
3. Ulmo J. *Eléments de statistiques*. Berger-Levrault, 1967: 32-34, 134-135.

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