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Alloy UNS N06058: A solution for demanding applications where common members of the Ni-Cr-Mo alloys experience their limits

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ABSTRACT

The high performance alloy UNS N06058 contains about 21 wt.-% chromium and at least 18.5 wt.-% molybdenum. It is the first member of the Ni-Cr-Mo alloys intentionally strengthened with nitrogen. Based in the combination of its alloying constitutes this alloy is highly resistant to oxidizing as well as to reducing corrosive media. Evidenced by the high Pitting Resistance Equivalent (PRE) number of about 86 the alloy UNS N06058 shows an outstanding resistance to localized corrosion as well.

The objective of this paper is to outline the characteristics of alloy UNS N06058 and therefore to highlight the successful use of it in demanding corrosive applications in the process industry and other sectors.

Main characteristics such as microstructure, mechanical properties and fabrication will be discussed. The very good weldability of alloy UNS N06058 has been verified by the German TÜV[1]. A matching filler metal, which is officially qualified according to AWS 5.14 (American Welding Society)[2], is available. In addition, prior work shows that alloy UNS N06058 can be reliably explosion clad. Furthermore, corrosion resistance determined under laboratory conditions as well as in field studies will be presented not only for the base material but also exemplary on welded and cladded samples. Examples of applications will complete the comprehensive overview of this work.

Key words: Ni-Cr-Mo alloy, UNS N06058, 2.4700, matching filler metal, corrosion resistance, mechanical properties, welding, explosion cladding, ISO corrosion diagram, sulfuric acid, hydrochloric acid, mixture acid

MOTIVATION FOR THE DEVELOPMENT OF ALLOY UNS N06058

The chemical process industry and other sectors are calling for highly corrosion resistant materials. When materials are needed for applications where harsh reducing as well as oxidizing environments occur and/ or high resistance against localized corrosion is necessary, alloys of the Ni-Cr-Mo family are a possible choice.

The development of the Ni-Cr-Mo alloys started with the alloy UNS N10002 (alloy C) in 1930. Due to processing difficulties caused by too high silicon and carbon contents, it was replaced in the 1960s by alloy UNS N10276 that contains significantly lower contents of these constitutes. This became possible because of the Argon Oxygen Decarburization (AOD) and Vacuum Oxygen Decarburization (VOD) manufacturing processes introduced at that time. From this time on the materials of this family contained about 0.04 wt.-% silicon and 0.005 wt.-% carbon. Their nominal composition with regard to their main alloying elements in order of their historical evolution are presented in table 1. The main area for application of alloy UNS N10276 is corrosive attack by reducing acids such as sulfuric acid, phosphoric acid, hydrochloric acid, and organic acids, even in the presence of halogens. The tungsten-free and low iron containing alloy UNS N06455 introduced in the 1970s offers significantly higher thermal stability and therefore better processability, but on the other hand the alloy is less resistant in prevailing reducing media. The alloy UNS N06022, containing a higher chromium content compared to the before mentioned alloys, was developed in the mid-1980s to improve the handling of oxidizing media. However, the molybdenum content was reduced from 16 wt.-% to 13 wt.-% and therefore 3 wt. % tungsten was added, which can only partly compensate the lower Mo-content. As a result, it is inferior to alloy UNS N10276 in strongly reducing media and in conditions of extreme crevice corrosion attack. In the early 1990s, the alloy UNS N06059 was introduced. It shows a chromium content of about 23 wt.-% and a molybdenum content of about 16 wt.-%. This alloy has outstanding resistance in a wide range of acids, for example mineral, mixed, organic and sulfuric, even if contaminated together with an excellent thermal stability.[3,4,5,6]

Table 1: Nominal composition of common Ni-Cr-Mo alloys in order of their historical evolution, adapted and updated from[4,6].

Alloy	UNS	EN	Main alloying elements Typical values in wt %					PRE*
			Ni	Cr	Mo	Fe	Others	
C-276	N10276	2.4819	57	16	16	6	3.5 W	75
C-4	N06455	2.4610	66	16	16	1		69
22	N06022	2.4602	56	22	13	4	3 W	70
59	N06059	2.4605	59	23	16	1		76
2120	**N06058**	**2.4700**	**59**	**21**	**19**	**≤1**	**0.075 N**	**86**

* **P**itting **R**esistance **E**quivalent = %Cr + 3.3 % Mo + 3.3 x 0.5 %W + 30 %N

The newest member of the C-family is alloy UNS N06058. The intention for its invention was the demand for a material for demanding applications where common Ni-Cr-Mo alloys experience their limits. The aim was to develop a material with further improved corrosion resistance in aggressive media. Its nominal chemical composition is shown in the last line of table 1. Alloy UNS N06058 has the highest molybdenum content so far compared to the other members of the C-family with about 19 wt.-%. It is also the first Ni-Cr-Mo alloy intentionally alloyed with nitrogen. Based in the combination of its alloying constitutes this alloy is highly resistant to oxidizing as well as to reducing corrosive media.[3,4,5,6,7,8]

A first hint regarding resistance to localized corrosion in halide-containing media is given by the empirical calculation of the so called Pitting Resistance Equivalent (PRE) Number which is determined from the alloys composition by the equation shown in table 1. Using this equation, the Ni-Cr-Mo alloys can be ranked. The higher the PRE value the higher the resistance to the testing corrosion media for example in green death solution. The PRE values for the Ni-Cr-Mo alloys are shown in the last column in table 1. Alloy UNS N06058 has the highest PRE value with about 86 indicating a higher resistance to localized corrosion compared to its alloy family members. [3,4,5,6]

CHARACTERIZATION OF UNS N06058

Chemical Composition

The chemical requirements of alloy UNS N06058 are listed in table 2. The data are taken from the material data sheet.[9]

Table 2: Chemical composition of alloy UNS N06058 (wt.-%).[9]

	Ni	Cr	Mo	Fe	Cu	Al	W	Co	Si	Mn	N	S	C	P
Min.		20.0	18.5								0.02			
Max.	bal.	23.0	21.0	1.5	0.5	0.4	0.3	0.3	0.1	0.5	0.15	0.01	0.01	0.015
Due to technical reasons this alloy may contain additional minor elements.														

Thermal Stability

Thanks to the simulation software JMatPro† (version 11) using the thermodynamic database TTNi-9, a theoretical prediction of the phases in the thermodynamic equilibrium (figure 1) and their formation kinetics (figure 2) for alloy UNS N06058 is possible. Figure 1 shows the different phases which can occur in the temperature range from 600 °C (1112 °F) to 1400 °C (2552 °F) in the thermodynamic equilibrium. The gamma phase forms the matrix of alloy UNS N06058, which means that the alloy has an austenitic microstructure over the complete calculated temperature range. At temperatures of 600 °C (1112 °F), the calculation via JMatPro† is predicting that the intermetallic rhombohedral μ phase of up to 29 wt.-% is present. It converts into the orthorhombic P-phase at about 905 °C (1661 °F). Its phase fraction decreases continuously, so that it reaches its minimum at about 1080 °C (1976 °F). Both phases are similar in their chemical compositions. They contain high contents of molybdenum, nickel and chromium. The significant difference between the two phases is their crystallographic orientation. Time-Temperature-Transition (TTT)-diagrams give hints regarding kinetics of the individual phases. In figure 2, the TTT- diagram of alloy UNS N06058 for 0.5 wt.-% phase fractions of intermetallic phases is shown. Between 700 °C (1292 °F) and 910 °C (1670 °F) the μ phase is the dominant intermetallic precipitate. Only at higher temperatures of up to 1060 °C (1940 °F) the P-phase is predominantly formed. The formation of carbides and carbonitrides such as $M_2(C,N)$, MC and M_6C are also of relevant importance for this alloy.[10,11]

To generate optimum mechanical and corrosion properties of wet corrosion materials the microstructure needs to be homogenous and preferably free of precipitates. This means that the precipitation of the before mentioned high molybdenum and chromium carbides, which can occur for example during hot forming or welding, needs to be avoided. Otherwise, the formation may lead to a strong molybdenum and chromium depletion in the surrounding grain boundary areas and thus lead to corrosion at the grain boundaries, which is called sensitization.[10,11,12]

† Trade name

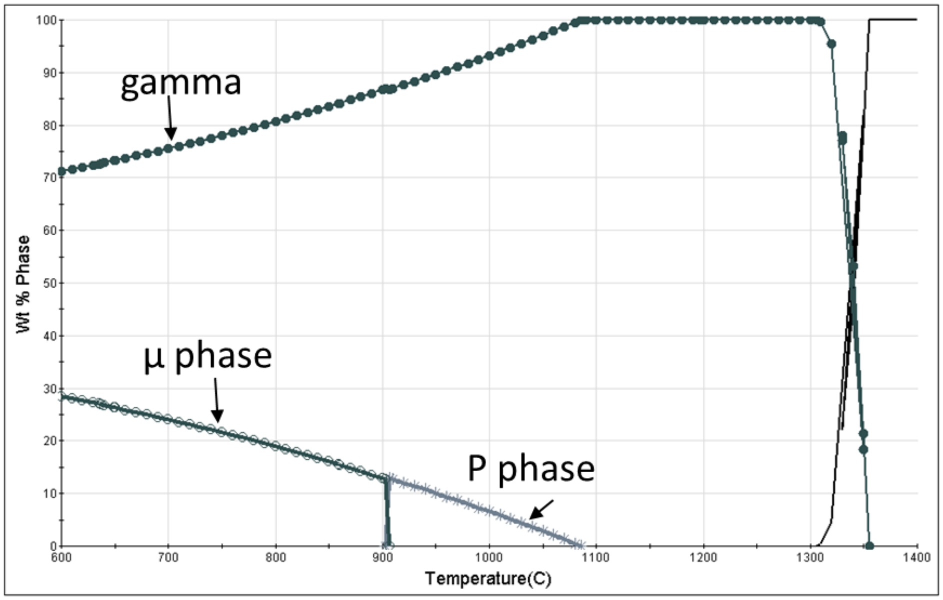

Figure 1: Phase-Diagram alloy UNS N06058 calculated with JMatPro.

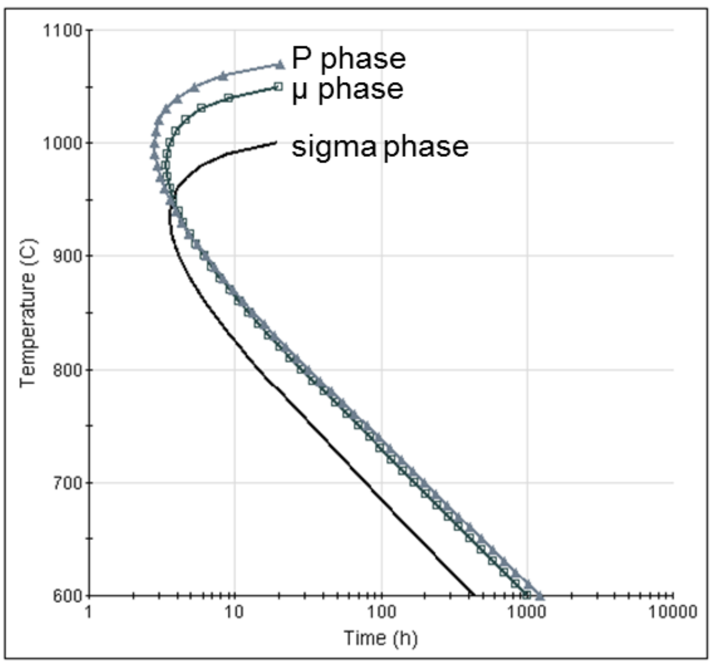

Figure 2: TTT-Diagram alloy UNS N06058 calculated with JMatPro.

Sensitization Behavior

A common test for the evaluation of sensitization degree with regard to intergranular corrosion (IC) for alloys high in chromium is ASTM G28, method A.[13] It is a standardized test in boiling 50 % sulfuric acid (p.a. grade) with an addition of 42 g/l $Fe_2(SO_4)_3$ x 9 H_2O, which gives the test solution an oxidizing character. The common criterion for susceptibility to intergranular corrosion is the penetration depth of 50 µm. The penetration depth needs to be determined via microscopic inspection after the corrosion testing.[10,11,12,13]

The corrosion rates determined in this media of properly manufactured and heat treated common Ni-Cr-Mo alloys with regard to their ratio of Cr/Mo+W are presented in figure 3. The corrosion loss obtained for alloy UNS N06058 is following exactly the correlation that has been found for Nickel alloys in this common test solution. With an increasing Cr/Mo+W ratio the corrosion loss decreases in this oxidizing media.[3,4,6,8] The test in common practice is often used for this kind of materials to indicate if the heat treatment has been conduted correctly. If conducted incorrectly, local chromium and molybdenum fluctuations are often present in the microstructure. These in turn lead to a drastic change in the corrosion loss in this test compared to the solution annealed and quenchend condition of the material.

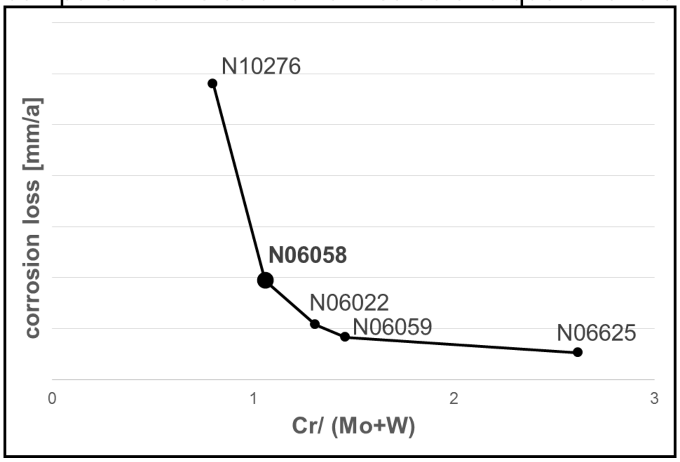

Figure 3: Corrosion loss determined acc. to ASTM G28, method A, of common Ni-alloys plotted with regard to their ratio of Cr/Mo+W.[6,8]

Investigations on the sensitization behavior in the sense of the before mentioned penetration depth of 50 µm criteria results in the time-temperature-sensitization diagrams, which are depicted in figure 4 for alloys UNS N06058, UNS N06059 and UNS N10276. As can be seen, the thermal stability for alloy UNS N06059 is outstanding, sensitization according to the 50 µm depth of attack criterion occurs first at an annealing time of about two hours. In comparison, alloy UNS N10276 sensitizes at much earlier times, whereas alloy UNS N06058 lies in between both alloys mentioned before. In the dotted areas, the values of corrosion loss and intergranular attack indicate that grains or whole grain layers have been dissolved in the microstructure.[6]

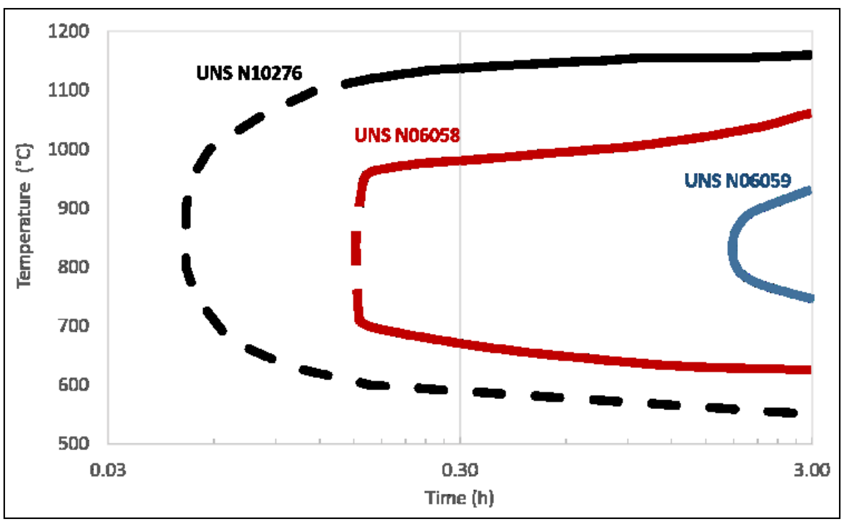

Figure 4: Time-temperature-sensitization diagrams of various Ni-Cr-Mo alloys, established acc. to ASTM G28, method A -> depth of intergranular attack > 50 µm, adapted and updated from[6].

To supplement the previous investigations, a comparison of alloy UNS N06058 and UNS N010276 with regard to the corrosion loss in this test solution at a temperature of 870 °C (1598 °F) is shown in figure 5. This is done for the comparative evaluation regarding the µ phase formation intensity, which can occur at this temperature according to the calculations by JMatPro as explained before. In comparison alloy UNS N10276 shows significantly higher corrosion loss, up to 10 times higher. Its corrosion loss rises strongly during the first 30 minutes, up to 60 mm/a. The corrosion loss of alloy UNS N06058 on the other hand increases constantly from 1.7 mm/a to a maximum of 8.5 mm/a.

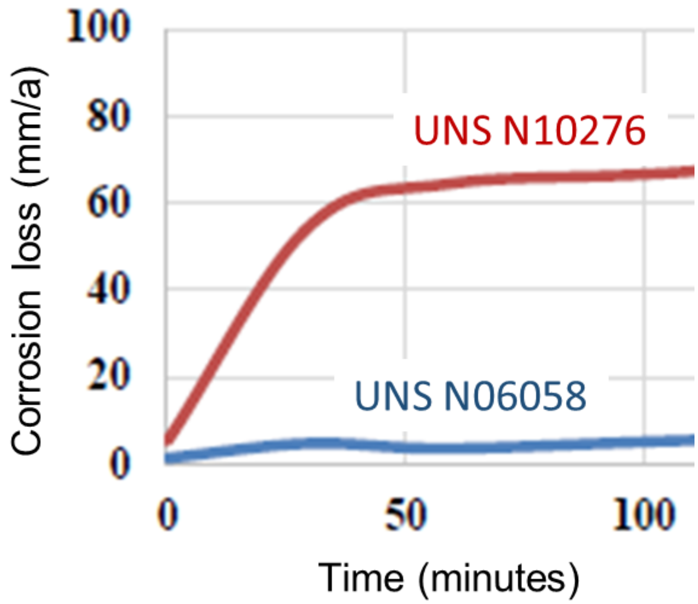

Figure 5: Corrosion loss of alloys UNS N06058 and UNS N10276 determined acc. to ASTM G28, method A, after annealing at a temperature of 870 °C at different annealing times.

Charpy Impact Test:
As a second method for detecting the sensitized state, the notched bar impact test was conducted. In addition, it illustrates the negative effects of intermetallic phases within the material. Specimens of UNS N06058 have been tested according to DIN EN ISO 148-1[14] with ISO-V-specimens after sensitization annealing. The tests have been done at RT on transverse samples. The value measured in the solution annealed condition is about 369 J. Intentionally sensitized samples have been heat treated at different temperatures afterwards to valuate which temperature would be necessary to achieve the initial toughness. At a temperature of 1140 °C (2084 °F) the V notch impact energy is beyond 369 J. By increasing the annealing temperature, the material experiences a steady increase in the notched bar impact energy until it exceeds its initial value at ca. 1160 °C (2120 °F). It can be assumed that most of the precipitates are dissolved at that point.

Precipitations of intermetallic phases and carbides needs to be avoided to achieve optimal performance of this wet corrosion alloy UNS N06058 as well as the other members of the Ni-Cr-Mo alloys. However, if formed the precipitations can be dissolved by solution annealing followed by quenching.[10,11] The recommended temperature range for solution annealing of the new material UNS N06058 is 1150 °C (2102 °F) – 1185 °C (2165 °F) [9], which was confirmed by the V notch bar impact measurements. The holding time depends on the material dimension. A successful solution annealed microstructure of alloy UNS N06058, which is the typical delivery condition, is demonstrated in figure 7. It shows equiaxed grains and a multitude of twinned crystals. Further, it is free of precipitates.

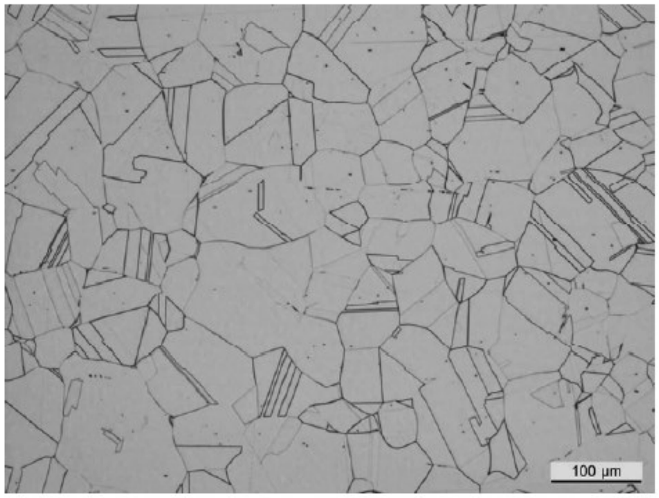

Figure 7: Metallographic inspection of alloy UNS N06058 in the solution annealed condition.[8]

Mechanical Properties

Table 3 shows the minimum mechanical properties at RT for alloys UNS N06058, UNS N06059 and UNS N10276 which are valid for plates or further strips in the case of the two first mentioned alloys in the solution annealed condition. These requirements are approved by TÜV and published in the VdTÜV-data sheets (german pressure vessel code) respectively.[1,15,16]

Table 3: Minimum mechanical properties at RT for solution annealed alloy UNS N06058 according to VdTÜV-material data sheet compared to other alloys of the C-family.[1,15,16]

UNS	R_m MPa	$R_{p0.2}$ MPa	A_{50} %	V-notched bar impact energy in J	Remarks
N10276	≥ 730	≥ 310	≥ 30	≥ 96	< 5 mm
	≥ 730	≥ 280	≥ 25		5 − 25 mm
N06059	≥ 690	≥ 340	≥ 40	≥ 180	Plate/ Strip ≤ 60 mm
N06058	**≥ 760**	**≥ 360**	**≥ 40**	**≥ 120**	**Plate/ Strip ≤ 30 mm**

Due to alloying with more molybdenum and some nitrogen, the measured and therefore minimum requirements of the strength values at RT of alloy UNS N06058 are comparatively higher. This results in clear savings potential with regard to design and dimensioning of plants and components. The impact energy requirements are highest for alloy UNS N06059, followed by alloy UNS N06058 and alloy UNS N10276.

Alloy UNS N06058 is covered in the following ASTM specifications: ASTM B564-18 (Forging)[17], B574-18 (Rod)[18], B575-17 (Plate, Sheet, Strip)[19], B619/B619M-17a (Welded Pipe)[20], B626-17a (Welded Tube)[21]. The ASME Code Case is also in proceeding.

Corrosion Resistance
The results of the corrosion measurements presented in this chapter are determined on plates in the solution annealed and quenched condition.

"Green death" solution
One option to obtain information about the resistance to pitting corrosion is to determine the critical pitting temperature (CPT). It is defined as the temperature at which pitting occurs on the material for the first time under the testing conditions. The CPTs of alloys with a high nickel content are commonly determined in a highly aggressive test solution called “green death”. The "green death" solution contains 7 % H_2SO_4, 3 % HCl, 1 % $CuCl_2$, 1 % $FeCl_3$ which simulates acidic condensates of the kind that occur in the flue gas ducts of coal fired power stations.[3] The measurements were started at a temperature of 80 °C (176 °F). The testing sample was immersed in the "green death" solution for 24 hours. Afterwards it was checked for the occurrence of pitting attack. If no pitting attack could be found, the measurement was continued at a temperature increased by 5 °C (41 °F). Alloy UNS N06058 has a PRE value of around 86, which is the highest value for common materials of the C-family as discussed before. In figure 8 common Ni-Cr-Mo alloys are plotted in ascending order of their PRE values. It shows that with increasing PRE value also a higher CPT was measured. This means that the material is more resistant to the test medium. As evidenced by this high empirical value alloy UNS N06058 shows the highest resistance against local corrosion in the tested media shown by the highest CPT of 145 °C (293 °F).[6,8] However, it should be noted that alloy UNS N06058 did not show pitting attack at 145 °C (293 °F), but the test is limited to this temperature.

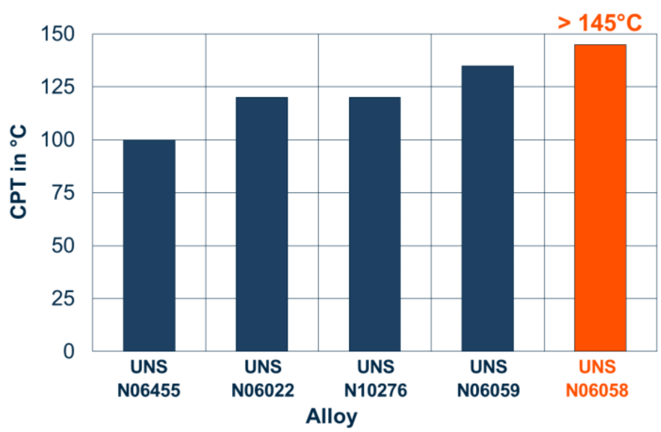

Figure 8: Critical Pitting Temperature (CPT) of common C-alloys determined in "green death" solution.[6,8]

Sulfuric acid
Immersion tests have been conducted in 90 % sulfuric acid at temperatures of 90 °C (194 °F) and 105 °C (221 °F) as well as in boiling sulfuric acid (pH = 1) with the addition of chlorides (70 g/l). The results of the measurements for different Ni-Cr-Mo alloys are presented in table 4. The new alloy UNS N06058 shows significantly lower corrosion losses under all tested conditions, even when contaminated with chlorides.[8]

Table 4: Corrosion loss of Ni-Cr-Mo alloys determined in different sulfuric acid solutions and testing temperatures.[8]

Medium	Temperature (°C/ °F)	Testing time (days)	**Corrosion loss (mm/a)**		
			UNS N06058	UNS N06059	UNS N10276
90 % H_2SO_4	90/ 194	21	0.04		1.17
90 % H_2SO_4	105/ 221	21	0.49		1.20
H_2SO_4 (pH = 1) + 70 g/l chlorides	boiling	21	0.08	0.34	0.55

Furthermore, the excellent resistance in sulfuric acid of alloy UNS N06058 is demonstrated by the isocorrosion diagram shown in figure 9. Isocorrosion diagrams give an initial orientation regarding the corrosion resistance of a material under the tested conditions. The concentration of the medium is plotted on the horizontal axis and the temperature on the y-axis. In such a diagram, the so-called 0.1 mm/a isocorrosion lines are plotted, which were determined by immersion tests of at least 120 h. Below these lines the material is to be regarded as technically corrosion resistant. The upper lines represent the 0.5 mm/a isocorrosion lines above which the materials are defined as non-resistant. Overall, the isocorrosion lines for alloy UNS N06058 are shifted to higher temperatures in comparison to alloy UNS N06059, which means that the material can be used under harsher conditions under the tested conditions. The 0.1 mm/a line proceeds well above 80 °C (176 °F) across nearly the whole concentration range in contrast to the 0.1 mm/a isocorrosion line of alloy UNS N06059 which decreases to ca. 80 °C (176 °F) at about 20 % H_2SO_4. Further the distance between both isocorrosion lines for alloy UNS N06058 is larger compared to alloy UNS N06059, which means that alloy UNS N06058 is less susceptible in the case of temperature fluctuations.[8]

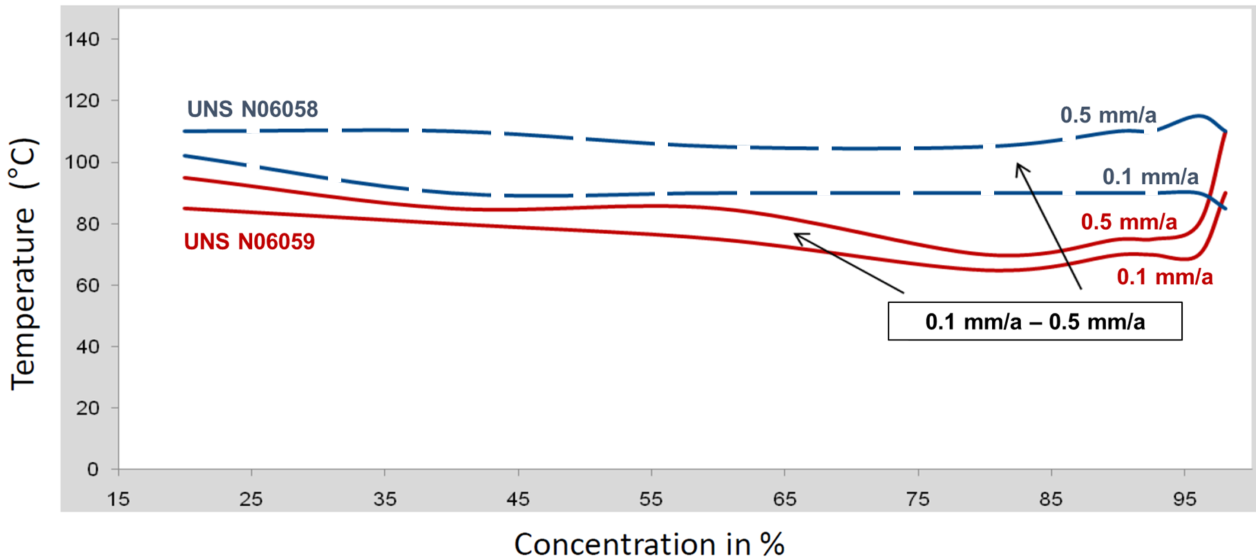

Figure 9: Isocorrosion diagrams of alloy UNS N06058 and alloy UNS N06059 determined in slightly aerated industrial grade sulfuric acid.[8]

Hydrochloric acid

A further reducing acid of technological relevance is hydrochloric acid. Immersion tests in hydrochloric acid have been conducted at three different acid concentrations and varied temperatures (table 5). In the entire testing range alloy UNS N06058 shows the highest resistance. For all tested conditions the other C-alloys show at least twice as high corrosion losses compared to alloy UNS N06058. That behavior reflects the higher molybdenum content.[8]

Table 5: Corrosion behavior in 24 hours immersion tests in hydrochloric acid (analytical grade)[8]

Medium	Temperature (°C)	Corrosion loss (mm/a)			
		UNS N06058	UNS N10276	UNS N06022	UNS N06455
10 % HCl	boiling	3.4	6.5	9.0	6.4
5 % HCl	boiling	1.6	3.6	6.9	3.79
2 % HCl	boiling	0.02	0.61	1.26	1.23

The isocorrosion diagram in aerated hydrochloric acid of alloy UNS N06058 is presented in figure 10. The considered concentration range of the hydrochloric acid was between 1.5 % and 37 %. Not only the 0.1 mm/a and 0.5 mm/a isocorrosion lines are shown but also the boiling curve of hydrochloric acid.

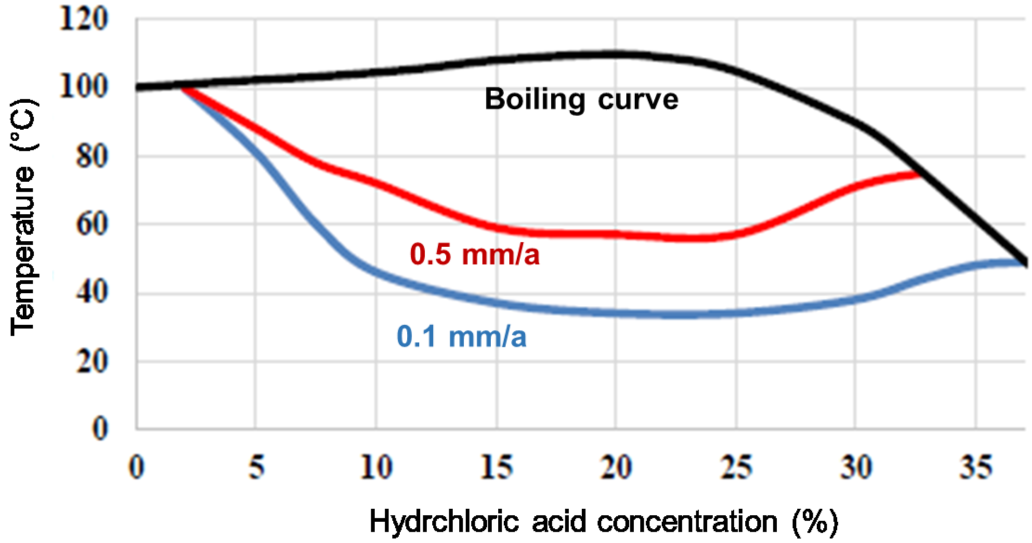

Figure 10: Isocorrosion diagram of alloy UNS N06058 in slightly aerated hydrochloric acid.

Organic acid

Further, the handling of organic acids especially as process mixtures are of great importance. Such mixtures can be found for example in the production of fine chemicals. For this purpose, immersion tests (24 h) were carried out on alloy UNS N06058 and on the traditional alloy UNS N10276 in 50 % acetic acid + 40 % formic acid + 5 % sulfuric acid (used at catalyst) at 95 °C (203 °F). Figure 11 shows the results where additionally the influence of aeration and de-aeration as well as the addition of contaminants such as ferric ions are investigated. The results show that the corrosion loss in this solution without additions is far below 0.1 mm/a for both alloys and no sign of local corrosion is visible. The influence of aeration on the corrosive attack in these organic acid solutions is negligible, while the effect of de-aeration by purging with nitrogen causes a reduction of the corrosion rates. Additions of iron ions up to 3 x 10^{-3} mol/l to the solution mixture have a smaller impact on the corrosion rate of alloy UNS N06058, but result in a significant increase of the corrosion rate of alloy UNS N10267. Overall, it can be highlighted that under the tested conditions the alloy UNS N06058 is more resistant than alloy UNS N10276.[7]

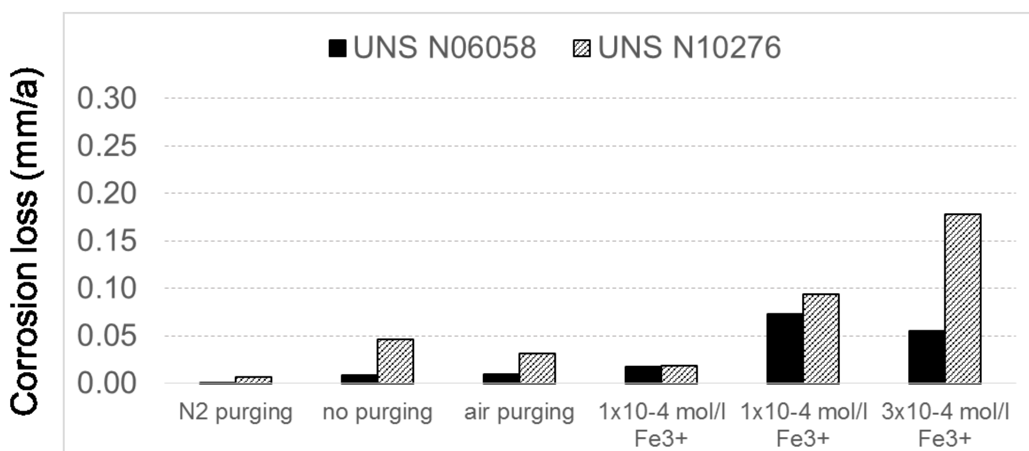

Figure 11: Corrosion loss of alloy UNS N06058 and UNS N10276 in 50 % acetic acid + 40 % formic acid + 5 % sulfuric acid at 95 °C (302 °F) under different conditions.[7]

Geothermal brine

Electrochemical investigations on alloy UNS N06058 in an artifical geothermal fluid simulating the natural conditions of the North German Basin at the Groß Schönebeck location demonstrate its suitability as a construction material in geothermal wells, see figure 12. The testing solution was a highly saline brine containing next to others 165 g/l chlorides and the testing temperature was about 150 °C (302 °F). The results show for alloy UNS N06058 a significantly higher critical transpassivation potential of 824 mV_{SHE} compared to the other tested materials which means that this alloy is the most resistant one under the tested conditions. It also surpasses alloy UNS N06059, which is also a candidate for such applications. The higher the Mo-content of the Ni-Cr-Mo alloys the better the corrosion behavior in such hot and highly concentrated brines.[22]

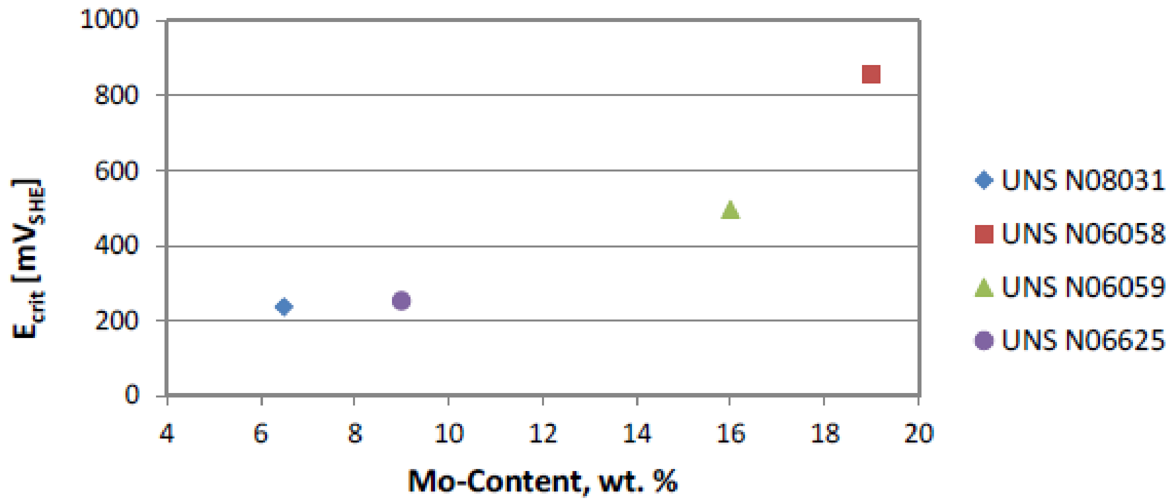

Figure 12: Critical transpassivation potential of various Ni-Cr-Mo alloys in non-aerated geothermal solution, 165 g/l Cl^-, 150 °C (302 °F) as a function of the Mo-content.[5,22]

Assessment of weldability

For the practical use of Ni-Cr-Mo alloys the question concerning weld-fabrication and corrosion resistance of the weldments is essential. Extensive investigations in this direction have been carried out on alloy UNS N06058. An overview is shown in table 6.

Table 6: Overview over experiences regarding welding with alloy UNS N06058 adapted and updated from[23].

Semi-finished product	Type of welding	Procedure	Example of application
UNS N06058 strip	Joint welding without filler material	Autogenous TIG	Longitudinal welded tubes
UNS N06058 plate + UNS N06058 (FM 2120)	Joint welding with filler material	TIG (man., mech.) GMAW (man., mech.)	Chemical reactors
UNS N06058 wire (FM 2120)	Overlay welding using wire	TIG (man., mech.) GMAW (man., mech.), SAW, ES	Corrosion protection for carbon steel
UNS N06058 plate + carbon steel plate	Explosion cladding	Explosion cladding	Corrosion protection for carbon steel

Longitudinally welded tubes of alloy UNS N06058 strips have been successfully manufactured by a major tube producer without using any filler material. The excellent performance of these welded tubes under extremely corrosive environments will be discussed later.

When it comes to weld joining of thicker walls, a filler material can be necessary. For alloy UNS N06058 a filler material of matching chemistry AWS A5.14 - ERNiCrMo-19[2] is available, see table 7. Especially in connection with the TÜV approval, the alloy UNS N06058 base metal (plate) joint welded with the before mentioned matching filler material, was extensively tested and ultimately also certified. For this purpose different weld procedures like tungsten inert gas (TIG) and gas metal arc welding (GMAW), which includes metal inert gas (MIG) respectively metal active gas (MAG), were applied in correlation with different material thicknesses up to 25.4 mm.

Table 7: Nominal chemical composition of matching filler material AWS A5.14 - ERNiCrMo-19.[23]

UNS	Main alloying elements Typical values in wt.- %				
	Ni	Cr	Mo	Fe	N
FM N06058	58	21	19.5	1	0.075

The corrosion testing was focused on the "as-weld" condition without any solution annealing or post weld heat treatment (PWHT). For both alloys UNS N06059 and UNS N06058 the CPT in green death solution have been determined on welded samples. The welding was done by TIG procedure with matching filler metal respectively. Common parameters have been used for each process. For alloy UNS N06059 CPTs of about 120 °C (248 °F) - 130 °C (266 °F) have been determined. This has also been reported elsewhere.[24] The CPTs for alloy UNS N06058 in this solution were about 135 °C (275 °F) - 145 °C (293 °F). In the unwelded state alloy UNS N06059 shows a higher CPT of about 135 °C (275 °F) compared to its welded state. For appropriate environments the use of alloy UNS N06058 as an overalloyed filler metal could level out this issue. For none of the investigated specimens a particular corrosion attack of the heat affected zone could be found indicating that alloy UNS N06058 is thermally stable and highly suitable for welding.

A cost effective alternative to the application of solid Ni-Cr-Mo alloys is the application of cladded material in form of e.g. weld overlay or explosion clad. Both procedures are feasible for alloy UNS N06058. In the first case the corrosion resistant material, alloy UNS N06058, is overlayed onto carbon steel. Essential for the corrosion behavior of an overlay weldment is prevention of iron dilution of the base metal.[24] As a short outcome, the overlay weldments UNS N06058 showed excellent resistance towards pitting corrosion. Furthermore, no pore formation or hot cracking was detected. More detailed information on this subject will be shown in the near future. An extensive work on explosion cladding of UNS N06058 has been given by Prothe et al.[6] The results show that UNS N06058 can be reliably explosion clad and are fully compliant with ASME Code. What is more, the corrosion resistance in media such as ASTM G28 A, sulfuric acid and "green death" solution is nearly the same as for the solid state.[5]

For all mentioned cases the weldability of alloy UNS N06058 has to be assessed as excellent.

Application

Due to the excellent resistance in aggressive media as well as the excellent fabricability, a wide range of demanding applications for alloy UNS N06058 are possible. This includes the handling of mineral acids such as sulfuric acid and hydrochloric acid as well as acid mixtures. Production and handling of halogenide-containing chemicals, equipment for organic synthesis and production of fine chemicals, sour gas and geothermal applications as well as for components in flue gas desulfurisation.[9] Not only investigations in the laboratory level have demonstrated its wide range of possible applications.

What is more, field test experience confirms its advantage for demanding applications among other Ni-Cr-Mo alloys. A mentionable example is the successful use of longitudinally welded strips made of alloy UNS N06058 which have been fabricated to a heat recovery system for a module in a flue gas desulfurization plant, see figure 13. Harsh environments are predominant (besides others: condensed sulfuric acid, chloride contaminations combined with temperatures above 100 °C (212 °F)). It has been in successfully use for more than four years. Therefore, it has surpassed other high-alloyed materials such as alloy UNS N06059, which has failed already after six month of usage, and also all non metallic solutions. A second example that can be highlighted is a plate heat exchanger for the chemical process industry to process a hydrochloric containing environment shown on the right side in figure 13.

Figure 13: Applications of alloy UNS N06058 for example as a heat recovery system in a FGD plant (left) or as a heat exchanger in the chemical process industry (right).

CONCLUSIONS

The superior corrosion resistance of alloy UNS N06058 in comparison to other materials of the Ni-Cr-Mo family was demonstrated by means of various laboratory tests and in field trials. Overall, the new wet corrosion material shows excellent corrosion resistance in the range from strongly reducing to moderate oxidizing media, as well as against local corrosion attack. Furthermore excellent weldability and fabricability is given.

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† Trade name

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