

NEW EXPERIENCES WITH EXPLOSION CLAD ALLOYS UNS N06058 AND UNS N06059

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ABSTRACT

Prior work showed that the Ni-Cr-Mo alloys UNS N06058 and UNS N06059 can be reliably explosion clad to carbon steel and are fully compliant with ASME Code. Additionally, corrosion tests in hydrochloric and sulfuric acid, in “green death solution” and further mechanical tests according to SA 265 (Nickel and Nickel-Base Alloy-Clad Steel Plate) have been conducted.

To fabricate equipment such as pressure vessels, explosion cladding is followed by shell and head forming. If requested by the codes, a post weld heat treatment may also be mandatory. After this sequence, the clad bond zone layer has been investigated with respect to mechanical properties and corrosion resistance.

Therefore, best practices for explosive cladding and head forming were identified and evidence was provided that the explosive cladding process does not affect the above-mentioned properties of Ni-Cr-Mo materials. The effect of the post weld heat treatment on the corrosion properties in hydrochloric and sulfuric acid was also investigated and differences between alloy UNS N06058 and alloy UNS N06059 could be detected.

Key words: explosion cladding, explosion welding, Ni-Cr-Mo alloys, UNS N06058, UNS N06059, corrosion resistance, heat treatment, thermal stability, sensitization, shear strength, vessel head forming, DetaClad, plating, hydrochloric acid, sulfuric acid

INTRODUCTION

Classification of the used clad materials and motivation for explosion clad trials

The alloys used as clad material for this study are members of the so-called “C-family”. It consists of Ni-Cr-Mo alloys, which are known for combining the corrosion resistance of Ni-Cr alloys in oxidizing media with corrosion resistance of Ni-Mo alloys in reducing media. As a result, these materials have proven to be extremely durable in a wide range of highly aggressive media. The development of these materials started in the 1930s with Alloy C. This alloy showed remarkable corrosion resistance in a wide spread of media, low sensitivity for pitting or crevice corrosion and virtual immunity to chloride induced stress corrosion cracking¹⁻².

With these properties, the alloy was well suited for applications in the chemical process industry, oil refining equipment, petrochemical equipment and many more applications in highly aggressive media. With the increasing demands in these application fields, new alloys needed to be explored by using new production processes such as the VOD (vacuum oxygen decarburization). Thus, purer materials could be produced leading to the development of alloys like UNS N06022 and UNS N10276 (nominal compositions see Table 1). These new materials were characterized by lower contents in carbon and silicon resulting from the new production-methods. By that, the binding of chromium in carbides could be decreased and the chromium content in the microstructural matrix was elevated. This resulted in a positive effect on corrosion resistance¹⁻².

Further development and increasing demands of the industry finally lead to the introduction of UNS N06059 and UNS N06058².

Table 1: Several nickel-chromium-molybdenum alloys of the C-family in order of their introduction as well as their nominal chemical composition and their Pitting Resistance Equivalent Number (PREN); adapted and updated from².

Denomination			Introduced	Main alloying elements, typical values, wt%					PREN ^{*)}
Alloy	EN	UNS		Ni	Cr	Mo	Fe	Other	
C-276	2.4819	N10276	1960s	57	16	16	6	3.5 W	75
22	2.4602	N06022	Mid 1980s	56	22	13	4	3 W	70
59	2.4605	N06059	Early 1990s	59	23	16	1		76
2120	2.4700	N06058	Early 2010s	59	21	19	≤1	0.075 N	86
*) PREN = %Cr + 3.3 (%Mo + 0.5 %W) + 30 %N									

The **UNS N06059**, VDM® Alloy 59⁽¹⁾, is the purest ternary alloy of the Ni-Cr-Mo alloys. The nominal composition is limited to the elements Ni (59%), Cr (23%) and Mo (16%), with an iron content below 1%. After its development in the 1990s, it had the highest PRE number of 76 in the C family. The chosen composition gives the alloy excellent resistance in reducing as well as in oxidizing media. In addition, it is also very resistant to localized corrosion such as pitting or crevice corrosion. Compared to the previous representatives of the C-family, UNS N06059 represents a significant improvement in resistance to uniform and local corrosion in a wide range of media. Figure 1 depicts the behavior of UNS N06059 and UNS N06022 in reducing media such as sulfuric acid and hydrochloric acid. Especially in the critical temperature range above 60 °C for highly concentrated sulfuric acid, the corrosion rate of UNS N06059 increases only moderately compared to UNS N06022³⁻⁶.

⁽¹⁾ VDM® Alloy 59 is a registered trade mark by VDM Metals International GmbH

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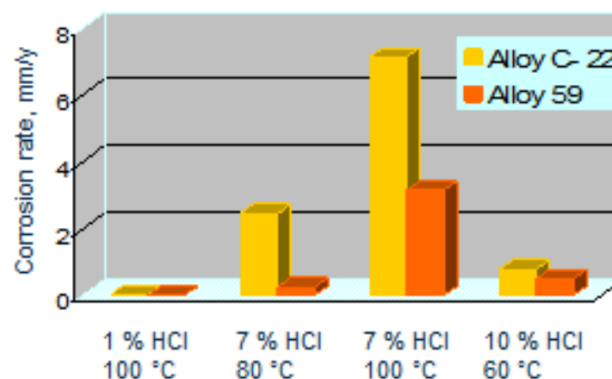
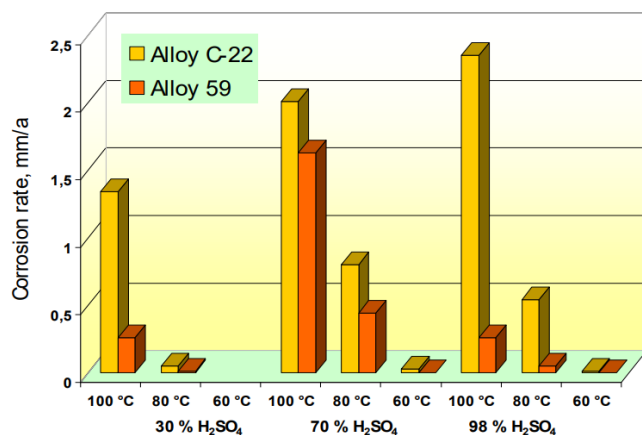


Figure 1: Corrosion tests carried out using UNS N06059 and UNS N06022 in sulfuric acid (left) and hydrochloric acid (right).

The thermal stability of the alloy is also excellent due to the absence of alloying elements such as W and Fe. In comparison with other representatives of the C-family, sensitization, as defined after exceeding an intergranular attack of 50 μm (IC-criterion) for the ASTM G28 A test, only occurs after two hours. In contrast, UNS N10276 already shows signs of sensitization effects after a few minutes (see Figure 2)⁷.

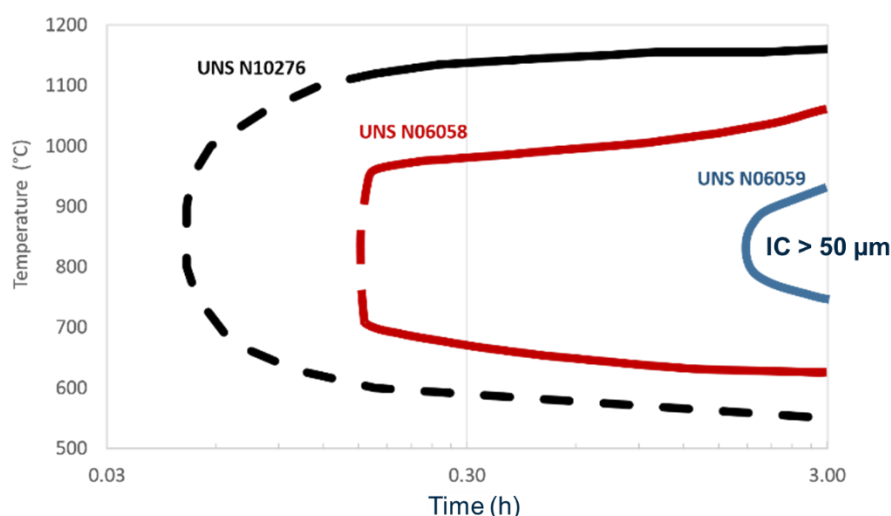


Figure 2: Sensitization curves of selected alloys from the C-family according to the IC-criterion (intergranular corrosion > 50 μm) of the ASTM G28 A test; taken and updated from⁸. Inside the depicted areas, values of mass loss or intergranular attack indicate damaged grain structures in the microstructure.

This results in a wide processing window, which underlines the good fabricability of the alloy. Thus, it is also possible to apply multilayer welds or necessary heat treatments with lower risk of sensitization of the microstructure. A matching filler material is used for welding. The AWS (American Welding Society) and German TÜV have qualified it for all common welding processes⁹⁻¹⁰.

These properties make it compatible with the production of chlorinated and fluorinated chemicals, production of HF, HCl-releasing drying processes or electricity carrying rolls in the electrolytic galvanizing of steel strip and many others, such as flare booms in the combustion of chlorinated hydrocarbons or multipurpose plants^{7, 11-12}.

The alloy **UNS N06058**, VDM® Alloy 2120 MoN⁽²⁾, is a further development of UNS N06059 and was introduced to the market in the early 2010s. This alloy is not only one of the youngest members of the C-family, but also the only alloy of this group to which nitrogen has been intentionally alloyed. The nominal composition can be seen in Table 1 and ensures that UNS N06058 achieves the highest PRE number in its class with 86. This is particularly due to the high molybdenum content of almost 19 wt. %. As a result, the material shows excellent corrosion resistance in both strongly reducing and oxidizing media. Investigations¹³ have also shown that the resistance to pitting and crevice corrosion are excellent (see Figure 3)¹³⁻¹⁵.

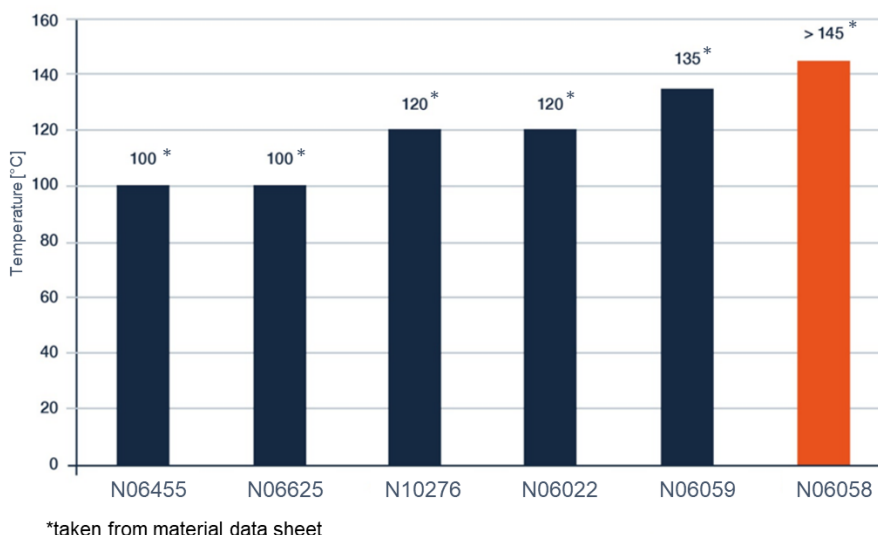


Figure 3: Critical pitting temperature in green death solution for selected alloys.

According to Figure 2, the thermal stability of UNS N06058 differs from that of UNS N06059, due to the materials faster sensitization kinetics. With respect to the IC-criterion of ASTM G28 A, a sufficiently large temperature window to enable good fabricability is given for this material. The significantly increased corrosion resistance resulting from the optimized composition makes the alloy particularly interesting for applications in the chemical process industry, flue gas desulphurization and others, where resistance in highly aggressive media and against pitting and crevice corrosion is required¹⁶.

The matching filler metal cannot only be used to weld UNS N06058 in accordance with the material, but it can also be used as an overalloyed filler metal for other materials. The filler metal is qualified according to AWS 5.14 and VdTÜV-Kennblatt for welding consumables 18954, 18965 and 18953¹⁶.

Preliminary investigations¹⁷ have shown that both alloys UNS N06058 and UNS N06059 can be explosion welded (here referred to as explosion cladding) to carbon steel in accordance with the requirements. During these investigations, matching parameters for head forming and the post weld heat treatment could be evaluated. The explosion cladding process is a high-speed welding operation similar to pressure welding with the difference that the bond zone is much thinner compared to conventional welding. In this process, a plate, which is the clad material, is bonded to a base plate¹⁸.

Basically, the clad material has different properties than the base material. In this case, the clad material has a higher corrosion resistance, while the base material, a low-alloyed carbon steel, is characterized by its strength. For a successful bonding of the plates, the clad plate is covered with explosives and positioned at a short distance from the base plate. Starting from the initiation point, the explosion is then set off, thus converting the chemical energy into kinetic energy, which leads to the top plate's acceleration

⁽²⁾ VDM® Alloy 2120 MoN is a registered trademark by VDM Metals International GmbH

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towards the base plate. When the two plates meet, the material is bonded at the interface. The process is shown in Figure 4¹⁸⁻¹⁹.

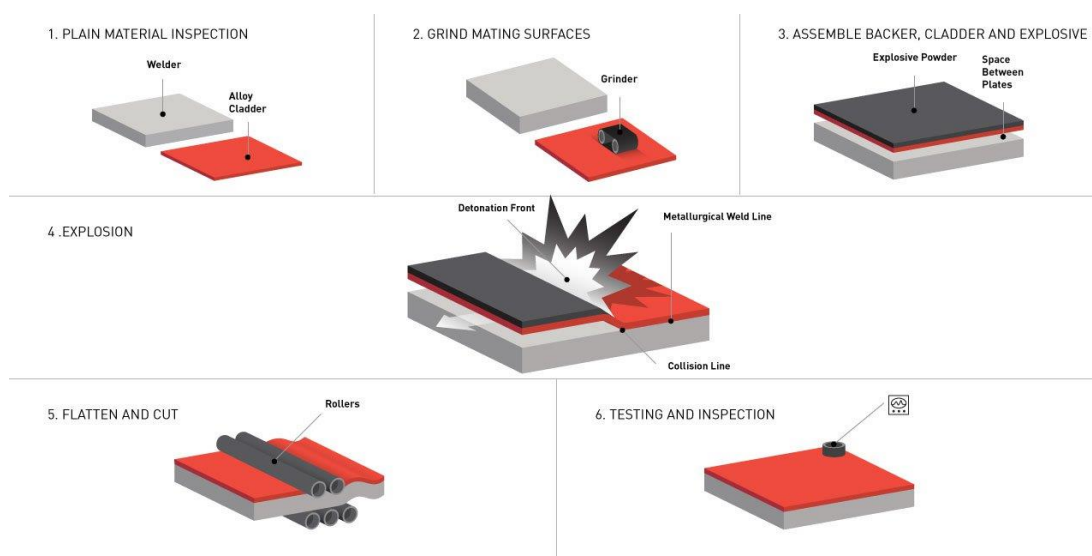


Figure 4: Simplified illustration of the DetaClad™⁽³⁾ explosion welding process (here referred to as explosion cladding) at NobelClad taken from²⁰.

The advantage of this process lies, among other aspects, in its cost efficiency. Equipment manufactured in this way are more cost-effective than equipment made of solid material from a thickness of 10 - 12 mm (0.39 – 0.47 in). Furthermore, desired material properties can be combined in this way.

This process is used in the production of pressurized vessels piping and/or heat exchangers that exceed a thickness of 12 mm (0.47 in). The relevant parameters for the explosion cladding process are given as explosion velocity, explosion energy and plate separation distance¹⁸⁻¹⁹.

EXPERIMENTAL PROCEDURE

Explosion cladding and head forming

To investigate the properties of explosion clad plates of the alloys UNS N06058 and UNS N06059 in more detail, one plate of each material with the dimensions 1000 x 2000 x 6 mm was seam welded in the center to form a plate of 2000 x 2000 x 6 mm. The matching filler metal UNS N06058 was used for this purpose. Producers qualified in accordance with ASME Code Section IX, using the GTAW process, performed the weld. The seam was welded without any problems and no defects were identified during penetrant testing or X-ray examination. This way it could be ensured that the two materials were exposed to exactly the same process conditions.

The welded plate was then explosion clad onto the base metal ASME/ASTM SA-516-70 carbon steel with dimensions 2000 x 2000 x 25.4 mm. The plate has been cladded using DetaClad™⁽³⁾, the proprietary explosion welding process at NobelClad. After cladding and flattening, an ultrasonic inspection was performed in accordance with ASME/ASTM SA-265 Class 1 specification. No defects were identified.

After a head blank with a diameter of about 1635 mm (64 in) was cut from the plate, the so-called head has been successfully formed at the company König & Co GmbH in Germany (see Figure 5). During the head forming process the material was annealed at 620 °C for 1.35 h and air cooled two times. A sketch

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