DVS - DEUTSCHER VERBAND FÜR SCHWEISSEN UND VERWANDTE VERFAHREN E.V.

(German Welding Society)

Welding of nickel and nickel alloys

Information Sheet

DVS 0601

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This Information Sheet has been prepared in cooperation with the manufacturers of nickel materials, nickel weld fillers, welding companies and acceptance organizations. It contains recommendations for the correct welding of nickel materials and information on fabrication, which takes account of the particular metallurgical properties of nickel materials.
If components, which are subject to acceptance or systems which require monitoring, are to be welded, refer to the technical regulations in Clause 9.

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1 Foreword

Nickel and most nickel alloys behave similarly to austenitic stainless steels with regard to welding. The non age hardenable solid-solution alloys can, provided the precautionary measures detailed in the following are followed, be joined using all electrical fusion welding processes and all resistance welding processes. Manual arc welding with a coated stick electrode, TIG and MIG shielding gas welding, plasma arc, laser as well as electron beam welding methods are preferred.

2 Basic materials

2.1 Definition

Nickel alloys are materials in which nickel forms the largest single constituent.

Table 1 contains a selection of alloys suitable for welding.

2.2 Standards and technical regulations

Nickel alloys are standardized worldwide. In Germany, the chemical composition of the basic materials is standardized
by DIN 17740 to DIN 17745 and the strength properties by DIN 17750 to 17754. The weld fillers [illegible] dealt with in DIN 1736 Parts 1 and 2. These will [illegible] future be superseded by European standards. The relevant VdTÜV Material Data Sheets are to be consulted where nickel and nickel alloys are used in the construction of pressure vessels (refer also to Clause 9).

2.3 Important groups of alloy

2.3.1 Pure nickel

Pure nickel is a bright silver metal with the atomic number 2[illegible] and atomic weight 58.71. It has a density of 8.9 g/cm^3.

Commercial grades of pure nickel have a degree of purity of [illegible] to 99.80% (DIN 17740). LC versions where the C-content is limited to a maximum of 0.02% are used for welded components. This content remains in solution; a higher content is precipitated out in the heat as graphite and impairs the ductility. Pure nickel is ferromagnetic at room temperature and becomes non-magnetic only above 3[illegible]0 °C. This means that no phase transformation takes place in the solid state. In the soft state it has a tensile yield strength of approximately 100 N/mm^2, a tensile strength of 400 N/mm^2, a high ductility and a high notched bar impact work even at very low temperatures (DIN 17750 to 17754). It can be easily worked in both the hot and cold states and is well suitable for welding. Nickel has a high corrosion resistance against various salts and alkaline media.

2.3.2 Nickel alloys

Nickel yields a series of other metal (e.g. Co, Cu, Cr, Fe, Mo) solid-solution alloys over a wide concentration range, which are used because of their resistance to corrosion and scale and their specific physical properties.

Nickel forms intermetallic phases with the elements Ti, Al, Nb and some other metals.

Nickel and copper form solid solutions in any mixture ratio. Compared with pure nickel metal, the NiCu alloys have the advantage of higher mechanical strength, even at high temperatures.

Nickel also produces solid-solution alloys with iron over a wide concentration range. Fe-Ni alloys are used particularly as physical materials. For welding technology, iron alloy with 36% Ni (invar) has, as a tough at sub-zero material, gained significance for diaphragm tanks of liquid gas tankers and for pipelines.

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With chromium, nickel forms alloys over a wide range. Nickel-chromium alloys have a high resistance to corrosion and scale. The nickel-chromium-iron alloys are technically close to the austenitic chromium-nickel steels (refer also to DIN 17742).

NiCr29Fe alloy with 29% Cr is becoming increasingly important. Because of its high chromium content it is more corrosion resistant than NiCr15Fe. Both materials are resistant to numerous reducing and oxidizing media and are largely immune to stress corrosion cracking.

Molybdenum is added to further improve corrosion resistance (DIN 17744). The NiCrMo alloys, e.g. NiMo16Cr16Ti (Code 2.4610) provide a substantial resistance to aggressive oxidizing media, such as mixtures of sulfuric and nitric acids.

The chromium-free alloy NiMo28 (Code 2.4617) has the highest resistance to reducing media (e.g. boiling hydrochloric acid). Table 2 provides an overview of later nickel alloys, particularly those alloyed with chromium and molybdenum.

Age-hardenable nickel alloys, which are characterized by their content of Al, Ti, Nb, form intermetallic compounds Ni_3Ti, Ni_3Al, Ni_3Nb (γ phase) with nickel. After elevated-temperature age-hardening, they are high-temperature resistant and are, for instance, used for parts of gas turbines. These alloys have only a limited suitability for fusion welding. Shielding gas welding and beam welding methods are normally used.

This group includes the heat resistant NiCr and NiCrCo alloys (e.g. NiCr20Ti (Code 2.4951), NiCr20TiAl (Code 2.4952), NiCr20Co18Ti (Code 2.4969)), which are welded only in the soft or solution-annealed state. Stress cracks can occur when welding in the hardened state. High weld voltages are to be avoided. Intermediate annealing may be necessary even after 1 to 3 passes.

The higher materials alloyed with Al and Ti are not suitable for fusion welding. The recommendations of the material manufacturer are to be followed when joining.

3 Suitability of nickel alloys for welding

3.1 General

Nickel and non age-hardenable nickel alloys can be welded using all arc welding methods and suitable systems, as are also used for austenitic stainless steels. The alloys are well suited to welding, but the following features must be taken into account.

3.2 Pore formation

Nickel and nickel alloys tend to form nitrogen pores. Therefore, weld additives containing gas-binding alloy elements are to be used (e.g. Al, Nb, Ti), to bind the nitrogen into solid nitrides (refer to DIN 1736). Care must be taken to ensure that the take-up of nitrogen is minimized (e.g. short arcs).

3.3 Susceptibility to sulfur

Sulfur strongly reduces the fusion point of nickel by forming nickel sulfide. At 2[illegible].5% S, a nickel-nickel sulfide-eutectic with a fusion point of 645 °C is present, as shown in the two-component diagram. The solubility limit for sulfur in nickel is 0.[illegible]5%; higher contents are precipitated as Ni_3S_2 – even from about 400 °C.

$Ni\text{-}Ni_3S_2$ is precipitated at the grain boundaries and under tensile stress can cause hot cracking and cold brittleness. Absolute cleanliness when welding and the careful removal of substances containing sulfur (grease, paint, etc.) from the area of the weld before welding are absolutely necessary, as is also an oven atmosphere which is completely sulfur free when annealing.

Low melting-point metals (e.g. lead, arsenic, zinc) can have similar negative effects.

4 General information on welding

Particular attention is to be paid to the cleanliness of the system and workpieces for all welding processes. The area of the weld must be clean on all sides and metallically bare. Oxide films which can arise due to prolonged storage of pre-fabricated parts before welding are to be removed by pickling (after degreasing) and then thoroughly rinsed with water (refer to Clause [illegible]).

During multi-pass welding, slag and oxide film is to be carefully removed from the individual beads. Very often this can only be achieved by grinding. The backing must also be clean. Brushing should be carried out using tools with stainless brushes or grinding wheels (resin-bonded) which are free of halogen, sulfur and iron. Solvents for degreasing and cleaning the weld must be approved (observe health regulations).

Sand blasting with iron-free blasting media is possible. Tools and working materials of stainless steels shall generally be used.

4.1 General information on weld preparation

The welding pool of nickel weld fillers is more viscous than that of steels. Therefore, larger included angles and a wider root opening are to be provided for certain root fusion. Thin plates up to approximately 1.5 mm thick are joined by flange welding or butt welding without fillers. Plates up to approximately 3 mm thick are joined using weld fillers by means of a square butt or V weld with a 70° [illegible]0° included angle. Thicker plates up to approximately 10 mm are joined using V welds with a 70° to 90° included angle. In the case of U butt welds (up to approximately 20 mm plate thickness) or double-U butt welds for larger plate thickness above 20 mm, an angle of bevel of approximately 15° shall be provided. This also applies as appropriate for other types of weld.

5 Welding processes and fillers

Coated stick electrodes, wire electrodes, welding rods and welding wires are standardized in DIN 1736 Parts 1 and 2. Other standards (USA) are AWS A 5.11 and AWS A 5.14. European standards (EN) are in course of preparation (table 3).

5.1 Manual arc welding

The basic coated stick electrodes are welded to the positive pole. All welding positions except vertically downward are possible, horizontal positions are desirable. Controlled heat input and the stringer technique are recommended. Welding is carried out using short arcs the same as with austenitic stainless steels. Arc striking pores can be avoided using a positioned plate or by striking the arc on the weld edge followed by overwelding. End-of-weld craters are to be carefully filled to avoid crater cracking; if necessary, the next bead is to be ground out before welding.

5.2 Tungsten inert gas welding (TIG)

The TIG method is preferred for thin cross sections (up to approximately 3 mm thick) and for root bead deposition (without back-step welding). The TIG weld metal also offers the maximum possible corrosion resistance. The weld fillers are standardized in DIN 1736. They contain gas binding additives (Ti, Al, Nb) with a composition which is otherwise the same as the associated base metals.

Welding is carried out using direct current with the tungsten electrode connected to the negative pole.