High-End torches for welding automation

WARRANTY
1 YEAR ON TCP

TBi RoboMIG

www.tbi-industries.com
Technical journal for welding and allied processes of the DVS – German Welding Society, Düsseldorf, the Professional Division of The Welding Institute, Cambridge, and the Institut de Soudure, Paris

Produced in Collaboration between

DVS  TWI  IS

NEWS

320  Changes in the management of the European Welding Association
320  EuroBLECH 2008: Jubilee show with record results
322  Åke Lindqvist elected new president of the International Federation of Robotics (IFR)

FROM COMPANIES

323  Monday morning syndrome – The effect of gas hoses on welding results
323  Small, precise and economical – New electron beam welding device on the market
325  More power to production with robot system
326  Short Messages
327  Products

EVENTS

329  First international conference on joining in the automotive industry held in Sattledt/Austria

WELDING PRACTICE

330  Information about practical welding

REPORTS

332  What does the DIN EN ISO 14 555.2006 standard stipulate in respect of quality assurance in stud welding? (Part 1)

SPECIALIST ARTICLES

David Yapp, Chang-Jing Kong
342  Hybrid laser-arc pipeline welding
Heinrich Hantsch, Eckard Beese, Klaus Timmer
348  Status of the development of an attachment nozzle for MAG welding with a dual gas flow
Emel Taban, Erdinc Kaluc, Eddy Deleu, Alfred Dhooge
354  Flux-cored arc welding properties of modified 12% Cr ferritic stainless steel

PUBLICATIONS

362  Books
361  Job offers
361  Editorial preview
362  Imprint/Ad Index

NATIONAL PAGES

338  WIS News – The Newsletter of the Professional Division of The Welding Institute
346  Information from the DVS – German Welding Society
Welding 1: Standards dealing with welding consumables and the destructive testing of welded joints


The handbook is an up-to-date reference collection of 44 standards on welding consumables, including European (EN) and International (ISO) standards. Familiarity with the characteristics of welding materials and welded joints is essential for ensuring safe welding procedures.

Welding 4: Selected standards for training welders


The handbook is a collection of 25 standards for use in the training of welding personnel. It contains essential standards covering fields such as welding consumables, materials, quality requirements, the testing of personnel as well as the design and construction of structural steelwork.

Arc welded projects, volume IV


This book features step-by-step directions for fun projects targeted at the home hobbyist and do-it-yourself-welder. Projects range from a gas-fired cooker trailer to a stainless steel pickup sander to a Dutch miser wood stove – all were created by welding students as entries for the foundation’s annual awards programs. The book includes contributing student and instructor names, school name and location, materials list, step-by-step instructions and full plans designs for each project.

List of companies in the advertisement section

You can also contact advertiser with an internet link via the internet address of DVS Media GmbH (http://www.dvs-media.info).

Air Liquide Welding France
F-Cergy Pontoise
IFC

Cranfield University

361

DVS Media GmbH
Düsseldorf
360,186

Gesellschaft für Waldrum

353

HBS Bolzenschweiß-Systeme

GmbH & Co. KG
D-Dachau
359

Linde AG
D-Pullach
BC

Mechafin AG
CH-Geroldswil
322

Messer Eutectic Castolin

Switzerland SA
CH-Jusanne
361

Orbimatic GmbH
D-Büseck
321

Bersed Siegmund GmbH
D-Grossatingen
351

Heinz Soyer

Bolzenschweißtechnik GmbH
D-Wörthsee
327

Tbi Industries GmbH
D-Fernwald
FC

TECHNODATA GmbH
D-Remscheid
336

Terms of Delivery: WELDING and CUTTING is published six times a year. Members of the DVS (German Welding Society) receive a discount on the regular subscription price. Subscription is possible either directly through the DVS Media GmbH or through your local bookstore. Single issues are available at a price of 19,-€ (plus shipping costs), the price for a one-year subscription for print is 112,-€ online plus print 150,-€ plus shipping costs 180,-€ within Germany, 260,-€ abroad; online 80,-€. Delivery by airmail is possible upon request. Professional or WJS Membership of The Welding Institute includes the subscription to WELDING and CUTTING.

The subscribers and/or the advertisers cannot assert any compensation claims for a reduction in services due to force majeure or to other circumstances for which the publishing house is not a fault (e.g. strike).

WELDING and CUTTING as well as all the contributions, figures and tables included in this journal are protected by copyright. With the exception of the statutorily authorised cases, any utilisation without the consent of the DVS Media GmbH is punishable.

When the work is accepted for publication, the author transfers to the publishing house the exclusive publishing rights for the period until the copyright expires. This transfer of rights relates, in particular, to the rights of the publishing house to reproduce the work for commercial purposes as a copy (microfilm, photo- copy, CDROM or other processes) and/or to include it in electronic or other databases. We do not accept any liability for manuscripts submitted without solicitation.

ISSN 1612-3433
Flux-cored arc welding properties of modified 12% Cr ferritic stainless steel

Dr.-Ing. Emel Tahan, born 1980, studied mechanical engineering at Ataturk University/Turkey and earned both her MSc and PhD degrees from the Mechanical Engineering Department of Kocaeli University/Turkey in 2004 and 2007 respectively, specialising in welding and weldability topics. She has been working in the same department of Kocaeli University since 2002 and has worked as a guest researcher at the Research Center of the Belgian Welding Institute between August 2005 and October 2006. She is member of DVS, AWS and the Mechanical Engineering Chamber of Turkey. Her objects of research are welding, weldability and materials science. She has been author and co-author of about 50 international and national papers including research and review articles, proceedings and three books related to advanced welding processes, weldability of stainless steels and friction stir welding.

Dipl.-Ing. Eddy Deleu graduated as civil engineer at the University of Ghent in 1973. He started his career at the Laboratory Soete for Strength of Materials and Welding Technology at the same university. In 1976 he became researcher in the field of strength of materials, fracture mechanics and weldability at the Research Center of the Belgian Welding Institute at Ghent. Since then he acted as project leader for several research projects supported by the Belgian and European Authorities especially on duplex and weldable 13 Cr supermartensitic and 12 Cr stainless steels. He published more than 50 papers and presented several papers at international conferences on topics like weldability and fitness-for-purpose.

Prof. Dr.-Ing. Alfred Dhooge is a mechanical engineer and qualified as International/European Welding Engineer. He has been director of the Belgian Welding Institute for more than 20 years and is now professor at the Faculty of Engineering at Ghent University, responsible for courses and research in metal construction and construction techniques.

Prof. Dr.-Ing. Erdinc Kaluc, born 1958, studied mechanical engineering at Kocaeli University/ Turkey and graduated with a Master's degree in mechanical engineering/materials science at Istanbul Technical University, Istanbul/Turkey. He earned his PhD in mechanical engineering/materials science at Istanbul Technical University, Istanbul/Turkey. Since 1995 he has been the director of the Welding Research Center of Kocaeli University. Since 1997 he has been working as professor in the department of mechanical engineering, engineering faculty at Kocaeli University. He is member of several organisations such as AWS, DVS, WIS and the international scientific board of international and national welding conferences of the Turkish Mechanical Engineering Chamber. He has more than 200 publications dealing with weldability and joining of materials. He is also known as author of eight books related to weldability of materials and advanced welding processes.

12% Cr stainless steels potentially with better weldability than either ferritic or martensitic types are widely used as low-cost, utility stainless steels due to their sufficient corrosion resistance in atmospheric and non-aggressive aqueous conditions in many applications such as coal and gold mining, sugar-processing industries, road and rail transport and power generation. In this study, a modified type of X2CrNi12 ferritic stainless steel conforming to 1.4003 in EN 10 088-2 and EN 10 028-7 and UNS S41003 in ASTM A240 with a lower carbon content (<0.01%) to improve the weldability has been used and the properties of flux-cored arc-welded 20 mm thick modified 12Cr plates were investigated. Joints were subjected to mechanical testing by means of Charpy impact, crack tip opening displacement (CTOD) fracture toughness, tensile and bend tests. Chemical analysis of the weld metal and microstructural examinations were carried out, including hardness surveys, ferrite content measurements and grain size analysis of various weld regions. To determine atmospheric corrosion resistance, salt spray and blister tests were carried out in order to investigate all aspects of the weld properties. The relation between the toughness and the microstructure is determined. Interpreting all the data obtained, it can be concluded that if the improved weldability of this modified 12% Cr stainless steel with a controlled chemical composition could be provided, higher productivity during welding would be enhanced and application areas would largely be extended as an innovative aspect.

Emel Tahan and Erdinc Kaluc, Kocaeli/Turkey, Eddy Deleu and Alfred Dhoooge, Ghent/Belgium

1 Introduction

Ferritic stainless steels include between 10.5 and 30% Cr with small amounts of austenite-forming elements such as carbon, nitrogen and nickel. Low chromium grades have fair corrosion resistance and low-cost fabricatability and have commonly been used in automotive exhaust systems. Since a fully ferritic structure has poor low-temperature toughness and poor high-temperature strength compared to austenite, these steels were considered as low-weldable steels and they have mostly been used for the applications without the requirement of welding. The importance of life cycle costs analysis and improved steel-producing technologies has increased the performance potential of lean-alloyed stainless steels. Advanced steelmaking technology now enables tight control of the composition and can provide extremely low levels of carbon and nitrogen with consequent improvement in the as-welded HAZ properties, as well as the reduction of chromium carbides which degrade corrosion performance [1...17].
12% Cr stainless steels were developed depending on the formation of austenite at high temperatures which then may transform to martensite on cooling in some predominantly ferritic steels. Close control of the carbon content and martensite/ferritic balance should be provided to avoid the extremes of completely ferritic or martensitic structures which also find interesting applications as a high-strength stainless structural steel. The development of these steels with low carbon and interstitials improving the weldability led to an increase in the engineering applications of such materials [1; 4; 11; 12; 16...25].

3Cr12 with a carbon level of 0.03% is the first generation of these steels which has good corrosion resistance in many environments providing considerable economic advantages over austenitic stainless steels and is named in ASTM A420 as UNS S41003 and in EN as Material Number 1.4003 [25...27]. In high-purity Fe-Cr systems, the gamma loop extends as far as about 13.5% Cr after which the structure is fully ferritic at all temperatures. Due to the low alloying content, 3Cr12 lies in the dual-phase region, hence it is variously described as ferritic or ferritic-martensitic 12% Cr stainless steel. The correct balance between ferrite-forming and austenite-forming elements is quite important and can be controlled using certain relationships based on the ferrite-forming or austenite-forming elements and heat treatment conditions. 3Cr12 provides an alternative which displays both the advantages of stainless steels and the engineering properties of carbon steels. It has not been designed to replace other stainless steels but has been developed to fill the gap between stainless steels and carbon steels. This combination opens up a wide range of applications, however attention must be paid to using the correct welding parameters to ensure good joint integrity. Relatively low fracture toughness levels in the weld HAZ have restricted the use of 3Cr12 steels where fatigue and impact loads are concerned [6; 19...36].

Due to the modern production facilities, modified X2CrNi12 ferritic stainless steel still conforming to grade 1.4003 in EN 10 088-2 and EN 10 028-7 and UNS S41003 in ASTM A240 with very low (<0.01%) carbon levels improving the weldability and the mechanical properties have recently been fabricated. The 1.4003 type of steels has mainly been used in materials handling equipment in corrosive environments but they are now used extensively in the coal-mining and gold-mining industries, also for sugar-processing equipment, road and rail transport, power generation and in aerospace engineering applications. This modified low-carbon X2CrNi12 stainless steel needs lower maintenance and coating costs, leading to significant economic and environmental advantages [12; 16; 19; 23; 25; 37...46].

In this paper, properties of flux-cored arc-welded 20 mm thick modified 12% Cr ferritic stainless steel joints have been investigated. Mechanical, Charpy impact and CTOD fracture toughness, microstructural and corrosion tests were carried out and the results and property-microstructure relation have been evaluated and discussed.

### 2 Material and experimental procedure

The chemical composition of the base metal obtained from the chemical analysis and the tensile properties are given in Table 1.

Flux-cored arc welding was accomplished by using a rutile E309LT0-4 flux-cored tubular wire with a 1.2 mm diameter shielded by an EN439-M21 oxidising gas mixture. The V-shaped plate preparation with an angle of 60° was filled in thirteen passes. A ceramic backing strip was used while the heat input varied between 0.82 and 1.38 kJ/mm.

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Cu</th>
<th>Ni</th>
<th>Mo</th>
<th>Ti</th>
<th>V</th>
<th>Al</th>
<th>Nb</th>
<th>N(ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.01</td>
<td>0.32</td>
<td>0.97</td>
<td>0.033</td>
<td>0.003</td>
<td>12.2</td>
<td>0.39</td>
<td>0.52</td>
<td>0.14</td>
<td>0.001</td>
<td>0.040</td>
<td>0.029</td>
<td>0.031</td>
<td>88</td>
</tr>
</tbody>
</table>

Yield strength (MPa) Ultimate tensile strength (MPa) % Elongation

Table 1. Chemical composition (in % by weight) and tensile properties of the modified 12% Cr ferritic stainless steel base metal.

Transverse full-thickness tensile specimens with respect to EN 10 002-1-EN 895 and cylindrical test samples completely positioned at the weld metal in the longitudinal direction in accordance with EN 10 002-1-EN 876 were extracted and tested at room temperature using a hydraulically controlled test machine. Transverse face and root bend test specimens with a nominal specimen width of 30 mm were tested with a mandrel diameter of 91 mm and with a bending angle of 180°.

Notch impact test samples were extracted transverse to the weld from both the face and root sides with notches positioned at the weld metal centre (WM), at the fusion line (FL), at the heat-affected zone 2 mm from the fusion line (FL+2 mm) and at 5 mm from the fusion line (FL+5 mm). Testing was carried out at −20°C, at 0°C and at 20°C. Testing was also carried out after a post-weld heat treatment of the samples at 750°C for 30 minutes.

The welds were investigated with regard to their full-thickness crack tip opening displacement (CTOD) fracture toughness properties at −20°C with reference to BS 7884. CTOD fracture toughness is expressed in millimetres and measured in three-point bending under static loading conditions. Similar to the Charpy test, CTOD samples were notched at the weld metal centre (WM) and fusion line (FL) and they were precracked. After CTOD testing, the fracture surfaces of the samples were examined by a scanning electron microscope (SEM).

FCA-welded joints of modified 12Cr stainless steel were cross-sectioned perpendicular to the welding direction for metallographic analyses. Specimens were prepared, polished and etched. Macrophotographs and microphotographs of the weld zones were obtained by a light optical microscope (LOM) with 100× magnification.
For the chemical analysis, longitudinal sections entirely located at the weld metal were prepared perpendicular to the plate surface. Three measurements were taken by glow discharge optical emission spectrometry and averaged for each element while nitrogen was determined by the melt extraction method. The ferrite content was determined by Ferritscope measurements across the weld metal. HV5 measurements were carried out over the weld cross-sections at the subsurface from both the face and root sides. According to the impact test results, ASTM grain size numbers were measured on the existing macrosections at the thickness positions from the subsurface to the mid-thickness to investigate for a possible correlation between the impact toughness and microstructure of the welds.

Salt spray and blister corrosion tests were executed to assess the resistance against atmospheric attack. Salt spray tests were done with reference to ASTM B117 on uncoated and coated corrosion samples for 350 and 1000 hours of exposure respectively. The coating consisted of a two-layer protection system which is used in practice by a railway coach manufacturer. The samples were provided with a cross-shaped scratch over the entire test surface across the weld and also with paraffin at the sawn and machined surfaces. This allowed an estimation of the resistance of the welds when the coating is accidentally damaged prior to or during operation. Salt spray testing was done in a 5% NaCl aqueous solution with a fog volume of 24 to 28 ml per 24 hours, a pH of 6.5 to 7.2 and at a temperature of 35°C. Blister tests were executed on coated samples prepared similarly to those for salt spray testing. Samples were exposed to real atmospheric conditions from their face side with the excess of weld metal for over 3000 hours at the centre of Ghent/Belgium with their test surface oriented to direct sunlight.

### 3 Results and Discussion

Transverse tensile specimens have shown an $R_m$ value of 503 MPa. The fracture of the welds occurred at the base metal, Fig. 1. Splitting of the base metal was observed close to the fracture surfaces parallel with the plate surface in accordance with the literature and is attributed to intergranular decohesion along ferrite-martensite grain boundaries \[13\]. None of the face and root bend samples which were prepared from each welded plate transverse to the weld seam failed during bending and no defects were revealed after testing up to 180°. An average $R_m$ value of 571 MPa was obtained during the tensile testing of the all-weld-metal cylindrical test samples due to the 309 austenitic type of filler metal.

The mean notch impact values of the joints expressed in J are illustrated on Fig. 2. If 27 J is considered as the required mean toughness, the welds failed mainly at the fusion line and at fusion line + 2 mm. Due to this, a post-weld heat treatment (PWHT) was applied and testing revealed improved toughness values, Fig. 2.

The CTOD test data for the FCA weld of modified 12Cr stainless steel is given in Table 2. In general, the WM toughness is good to excellent which is most surely attributed to the austenitic filler metal used. And an FL CTOD fracture toughness of approximately 0.110 mm was determined except one sample. SEM fractographs with 1000× and 500× magnification of CTOD samples were illustrated on Fig. 3. As clearly seen, ductile fracture was observed for the samples notched at WM with fair CTOD test results and ductile brittle fracture was determined on the samples notched at FL which have relatively lower values.

### Table 2. CTOD fracture toughness at –20°C of the 20 mm thick FCA weld

<table>
<thead>
<tr>
<th>Notch position</th>
<th>CTOD (mm)</th>
<th>Failure mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>WM 0.230</td>
<td>Maximum force plateau</td>
<td></td>
</tr>
<tr>
<td>WM 0.191</td>
<td>Maximum force plateau</td>
<td></td>
</tr>
<tr>
<td>WM 0.196</td>
<td>Maximum force plateau</td>
<td></td>
</tr>
<tr>
<td>FL 0.033</td>
<td>Pop-in</td>
<td></td>
</tr>
<tr>
<td>FL 0.125</td>
<td>Fracture</td>
<td></td>
</tr>
<tr>
<td>FL 0.104</td>
<td>Fracture</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3. Chemical analysis of the weld metal.

<table>
<thead>
<tr>
<th>C %</th>
<th>Si %</th>
<th>Mn %</th>
<th>P ppm</th>
<th>S ppm</th>
<th>Cr %</th>
<th>Cu %</th>
<th>Ni %</th>
<th>Mo %</th>
<th>Ti ppm</th>
<th>V ppm</th>
<th>Al ppm</th>
<th>Nb ppm</th>
<th>N ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.03</td>
<td>0.53</td>
<td>1.64</td>
<td>210</td>
<td>80</td>
<td>24.1</td>
<td>0.13</td>
<td>11.3</td>
<td>0.09</td>
<td>130</td>
<td>1020</td>
<td>310</td>
<td>40</td>
<td>314</td>
</tr>
</tbody>
</table>
The microstructural investigation was carried out on the metallographic specimens of the joints using an LOM with 200× magnification. Relevant macrographs and micrographs are given on Fig. 3. The experimental data obtained from the chemical analysis for the all weld metal is given in Table 3.

The investigation of the weld zones has been performed from the base metal (BM) across the heat-affected zone (HAZ) to the weld metal (WM) respectively. Unlike the HAZ for plain carbon steels, the HAZs for 12% Cr stainless steels have two visually distinct zones; the high-temperature HAZ (HTHAZ) and the low-temperature HAZ (LTHAZ). The HTHAZ frequently consists of coarse-grained δ ferrite, with islands of martensite at the grain boundaries. If the material temperature reaches 1,050°C within 1 to 2 s, no reversion to γ will occur and the δ ferrite structure will be maintained to room temperature. However, material which has been heated above the Ac1 but below the Ac5 will contain significant fractions of γ which will transform to martensite, resulting in a tough fine-grained structure [19; 28]. On the micrographs as illustrated on Fig. 4, grain coarsening has been observed mainly in the HTHAZ and some martensite islands have been observed. According to the results of impact testing, it could be concluded that the grain coarsening of the welded joints has affected the impact toughness.

The ferrite content of the weld metal of the samples prepared from the related welds was measured by Fisher Ferritscope and the data is given in Table 4. As seen from the table, the ferrite content of the weld metal was measured between 15 and 20% due to the austenitic type of filler metal. Low-carbon 12% Cr steels have the tendency to transform to ferrite in the HTHAZ of fusion welds resulting in grain coarsening and, in addition, in the toughness reduction [12]. Considering this, ASTM grain size numbers from both the left and right sides of the HAZ were measured on the existing macrosections at the HAZ close to the fusion line from the subsurface to the mid-thickness to investigate for a correlation between the impact toughness and the grain size of the welds, Table 5 and Fig. 5.

It is emphasised that fine-grained microstructures have high ASTM grain size numbers (i.e. between 7 and 10) while coarse-grained microstructures are identified by low ASTM grain size numbers (i.e. between 1 and 3). In general, a poor fusion line toughness corresponds with coarse grains. Grain size analysis of the FCA welds of 12Cr stainless steel reveals that there has been grain coarsening of HTHAZ with low ASTM grain size numbers re-
sulting in low toughness data. Meyer and du Toit [35] mention that the ferrite grain size has a marked effect on the impact properties of the HAZ. The ductile-to-brittle transition temperatures (DBTT) of 12% Cr steel increase with the ferrite grain size [12; 47]. A fine grain size and elimination of low interstitial element contents by proper heat treatment enhance the ductility and the toughness. A fine grain size helps to enhance the toughness properties. As seen from Table 5 and Fig. 5, the more the grain size number increases, the microstructure has finer grains and the toughness generally increases. The graph on Fig. 5 reveals the relation between the toughness and the microstructure (e.g. grain size) as parallel lines of the related toughness and grain size data.

Hardness measurements carried out over the weld cross-sections are illustrated on Fig. 6. The WM hardness for the welds varies between 170 and 230 HV5. The maximum hardness is about 280 HV5 and was measured at the HAZ of the welds. Photographs of uncoated and coated samples are shown on Fig. 7 after exposure times of 350 and 1,000 hours for salt spray tests and of 3,120 hours for blister tests.

350 hours of exposure of the uncoated salt spray test samples showed that the FCA weld revealed deterioration starting mainly from the HAZ. The long-term (1,000 hours) salt spray corrosion behaviour of the coated sample heavily scratched across the weld revealed some corrosion products only at the scratch. Obviously, the coating provides good protection for the weld as, in general, only scratched regions were deteriorated. From Fig. 7c, it became apparent that the weld has been found to be resistant to atmospheric attack over a period of 3,120 hours even when damaged by a severe scratch across the entire welded joint.

4 Conclusions

The following conclusions have been drawn from this research work: Modified X2CrNi12 ferritic stainless steel complying with EN 10088 fabricated economically with a low level of carbon and impurities could be joined in a defect-free way by flux-cored arc welding. No defects have been observed after bending. The tendency to grain coarsening at the HTHAZ has no adverse effect on the tensile and bend properties but the HTHAZ impact toughness mainly decreases and depends on the amount of grain-coarsened microstructures. However, the HAZ toughness was improved by PWHT for 30 minutes which is promising. Microscopic investigations have shown that, if the grain coarsening could be restricted, welds would be tougher. The hardness at the HAZs of this steel can easily be limited to 300 HV5 in accordance with the recommendations in the literature. Good atmospheric corrosion resistance is provided by the coating for both the salt spray and blister test sam-

---

**Fig. 6.** HV5 graph of FCA weld-modified 12Cr stainless steel.

**Fig. 7.** Corrosion photographs of FCA weld-modified 12Cr stainless steel; a) uncoated salt spray samples after 350 hrs, b) coated salt spray samples after 1,000 hrs, c) coated blister samples after 3,120 hrs.
Due to the advances in the production of such a lean type of stainless steel with low carbon which provides better weldability at a reasonable cost and causes lower maintenance costs than structural carbon steels and because it is less expensive than the austenitic grades with attractive strength properties, this modified 12% Cr stainless steel can be classified as a cost-effective link between these types. In case the improved weldability of this modified 12% Cr stainless steel could be provided with a controlled chemical composition and delivery condition leading to higher productivity during welding, structural application areas would largely be extended in the near future as an innovative aspect.