A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 60 2015 Issue 2
DOI: 10.1515/amm-2015-0192

J. SŁANIA*,♯, R. KRAWCZYK*, S. WÓJCIK**

QUALITY REQUIREMENTS PUT ON THE INCONEL 625 AUSTENITE LAYER USED ON THE SHEET PILE WALLS OF THE BOILER'S EVAPORATOR TO UTILIZE WASTE THERMALLY

WYMAGANIA JAKOŚCIOWE STAWIANE POWŁOCE AUSTENITYCZNEJ INCONEL 625 STOSOWANEJ NA ŚCIANACH SZCZELNYCH PAROWNIKA KOTŁA DO TERMICZNEJ UTYLIZACJI ODPADÓW

Quality requirements and tests taken on the surfacing layer Inconel 625 are presented in the article. The reasons of using surfacing layer Inconel 625 and technologies of its making with a particular emphasis on the CMT method are described. Quality requirements for the surfacing weld Inconel 625 are provided. Basic requirements included in the Merkblatt 1166, as well as additional requirements, which are reflected in the technical specifications of the boilers' producers are specified.
Keywords: surfacing by welding, surfacing layer, incinerator

Przedstawiono kryteria jakościowe jakie powinna spełniać powłoka Inconel 625 oraz badania jakim jest poddawana. Omówiono powody dla jakich stosowana jest powłoka Inconel 625 oraz technologie jej wykonywania przy szczególnym uwzględnieniu metody CMT. Opisano wymagania jakościowe dla napoiny Inconel 625. Zaprezentowano zarówno wymagania podstawowe zawarte w Merkblatt 1166 oraz wymagania dodatkowe, których odzwierciedleniem są specyfikacje techniczne wytwórców kotłów.

1. Introduction

Growing environmental awareness which aims at reducing a negative influence of human on a natural environment finds a way through a need to run a reasonable waste management. One of the elements of waste management is a reduction of an amount of waste, which is dumped on the rubbish dumps, and treating it as a resource, which should be properly managed.

One of the methods of waste management is incinerating it in the boilers designed for a thermal waste utilization. It has twofold advantages: on one hand, while incinerating a volume and bulk of waste is diminished on the rubbish dumps, and on the other hand, obtained heat is used to produce electrical energy and heating.

Incinerating waste is connected with producing aggressive gasses and deposits, which in the high temperature causes a high-temperature corrosion. It attacks surfaces of the boiler and results in further degradation. Taking into account an increase of elements of the boiler's durability, which are susceptible to damages, they became to be covered with heatproof materials in order to be protected against a high-temperature corrosion. One of the above materials is an alloy based on the nickel matrix called Inconel 625.

A development of surfacing by welding, and aiming at maximising corrosion resistance of a layer, caused an increase of a quality requirements put on a surfacing weld Inconel 625.

2. Use of Inconel 625 austenite surfacing welds in boilers used to thermal waste utilization

Humans became to have a greater influence on the surrounded natural environment together with a development of civilization. This development was and still is often very negative. A negative influence is seen in a continuous production of waste, which through ages became bigger and bigger. Till recently duping waste has been the main method of waste management. On the same time an environmental awareness has been growing as well as an opinion that care about natural environment needs a reasonable waste management.

In order to reduce an amount of waste dumped on the rubbish dumps a process of incinerating became to be introduced. At present, systems of incinerating waste reduce about 80% of an amount of waste (without slag treatment), and thanks to slag treatment an amount of waste can be reduced up to 95%. On the same time, reduction of the mass reaches the level of 60-70% [1].

Incinerating is a chemical process of oxidising organic elements of fuel. In the process a considerable amount of heat is released. A development of civilization is connected with an increase of different types of industrial and household waste. Waste due to the content of organic elements has a significant energy potential, which can be considered as a renewable source of energy. At the same time, as a result of

* CZESTOCHOWA UNIVERSITY OF TECHNOLOGY, FACULTY OF MECHANICAL ENGINEERING AND COMPUTER SCIENCE, 69 J.H. DĄBROWSKIEGO STR., 42-200 CZĘSTOCHOWA, POLAND
** BOILERS FACTORY "SEFAKO" S.A, 9 PRZEMYSŁOWA STR., 28-340 SĘDZISZÓW, POLAND
♯ Corresponding author: jacek_slania@poczta.onet.pl

incinerating a problem of dumping waste is greatly reduced, and an energy included, is regained. In the above meaning waste is one type of renewable sources of energy [2].

A result of a thermal waste utilization is obtaining heat, which can be used to produce electrical energy or to power heat distribution networks. One of the biggest heat distribution networks in the world, which spreads on the area of about 50 km, is powered in 30% by three incinerate plants with an energy regain. It is situated in Copenhagen, and is a part of the Danish energy policy, which aim is to diminish a need for fossil fuels, and to increase power independence of the country [3].

A content of municipal waste, and its heating value considerably depends on the type of the land development where it is made (rural or urban), and a part of the year (summer or winter). Moreover, a level of an environmental education, which is shown in sorting waste according to its type in the places of its collection, has a key impact on the waste content. It was proved on the base of an analysis that a heating value for the municipal waste collected in Warsaw was 12,87 MJ/kg. On the other hand, waste collected in the rural areas had a heating value on the level of 11,83 MJ/kg [4]. It is equal to a European average which ranges between 8 to 14 MJ/kg [5].

A usage of a thermal waste utilization to produce electrical and heat energy requires specific technologies of an energy production. Numerous problems appear, e.g. an excessive high-temperature corrosion in aggressive burnt gasses [6].

A development of energetic technologies on the base of incinerating waste and biomass, introduced new requirements which relate to a resistance of materials to high-temperature corrosion in an aggressive environment including sulphur and chlorine [7].

A speed of corrosion is increased by the growth of a content of NaCl in the deposits that occur on the water-wall of the boiler. Corrosion products are scale shaped, and easily fall from a surface of metal, and as a result do not have any protective properties. Chlorine is situated in the area of deposits directly meeting a material of a pipe intensifying a process of destroying a material along the grain boundaries (Fig. 1) [7].

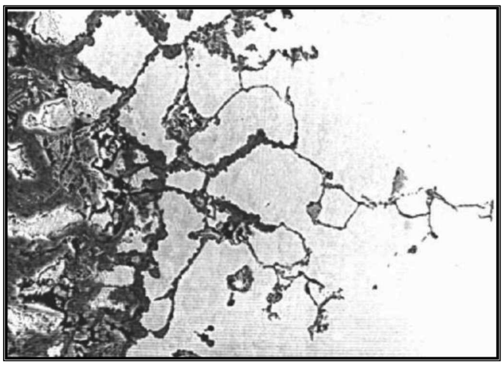

Fig. 1. Corrosion on the ferrite grain boundaries [6]

Another significant type of corrosion which occurs in the boilers used to utilize waste thermally is so called sulphur corrosion. Sulphur, which appears in the chemical compounds with sodium and potassium such as Na_2SO_4 and K_2SO_4, is not directly aggressive due to a high melting temperature (884°C for Na_2SO_4 and 1069°C for K_2SO_4). But pyrosulfates and trisulfates which are made from sodium and potassium sulfates with a use of SO_3 are aggressive to metal because they destroy a protective layer of oxides of an evaporator (Fig. 2) [8].

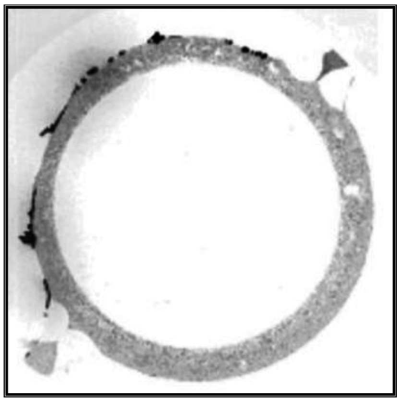

Fig. 2. Distribution of sulfides (Baumann printing) on the radiant tubes of the boiler on the side of an influence of burnt gasses [6]

Commonly used pipes of sheet pile walls type P2235GH or 16Mo3 in the power industry do not show enough resistance to corrosion in a particularly aggressive environment which is present in the chamber used to incinerate waste. Corrosion tests done both in the laboratory an also in the real incinerating plants show that the biggest resistance to corrosion is characterised by those alloys and steel which have an austenite structure and a considerable content of alloy elements increasing heat resistance. On the other hand, all types of steel with a low content of chromium have the lowest resistance to corrosion [7].

In order to increase a resistance to corrosion of boiler's elements the most susceptible to corrosion during incinerating waste, they are covered with the layers of special heat resistance alloys. Thus, durability of the above elements is longer. Surfacing by welding using heat resistance alloys is a compromise which ensures on one hand a proper anti-corrosive protection, and on the other hand a reduction of the materials' costs.

The most widespread alloy used to surface by welding the boiler's elements which are used to utilize waste thermally is an alloy based on the nickel matrix called Inconel 625. A chemical composition of this alloy is provided in the Table 1.

Aiming at making surfacing welds with a possible the lowest content of iron on the surface causes that it is required from the materials used to surface by welding the lowest content of iron in the chemical composition. Therefore, an amount of iron in offered wires and rods usually does not exceed 2%, and often is below 1%. A content of iron in a filler material is one of the major factor which has an influence on the final content of iron on the surface of a surfacing weld (additional factors are a linear energy of an arc and cooling surfaced by welding elements during welding).

TABLE 1

Chemical composition of Inconel 625 alloy [%]

Nickel	Chromium	Iron	Molybdenum	Niobium	Coal	Magnesium	Silikon	Phosphorus	Sulphur	Aluminium	Tytanium	Cobalt
min. 58	20-23	max. 5	8-10	3,15-4,15	max. 0,1	max. 0,5	max. 0,5	max. 0,015	max. 0,015	max. 0,4	max. 0,4	max. 1

Source: www.specialmetals.com

A reason to decrease a content of iron in a surfacing weld is an increase of resistance to corrosion. There is a noticeable relationship between a content of iron and resistance to corrosion despite a quality of the surface of the surfacing weld. Laboratory tests done for 750 hours in the temperature 800°C in the corrosive atmosphere, which is close to this existing in the boiler (N_2+9% O_2+ 0,08% SO_2 + 0,15% HCl), showed that an increase of an iron content on the surface of the surfacing weld decreases resistance to corrosion. Exceeding a value of 10% of iron content can cause that a cracked and peeled layer of iron oxides (Fe_3O_4) appears instead of a protective layer of chromium oxides (Cr_2O_3) on the surface. It does not protect against further oxidizing (Fig.3) [9].

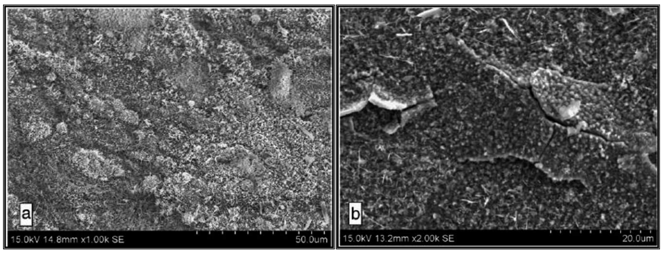

Fig. 3. Surface welded by Inconel 625 alloy after a high-temperature corrosion tests [9]: a) content of Fe 2,5%, b) content of Fe 10%

Anti-corrosive properties of Inconel 625 alloy are used for protecting these elements of the boiler which are the most susceptible to high-temperature corrosion. In order to extend durability of the elements, they are surfaced by welding by Inconel 625 alloy. In the picture nr 4, a typical area of surfacing by welding is presented, including sheet pile walls of the first, and second draught (front wall, left and right side walls, partition wall 1-2 draught, partition wall 2-3 draught, floor of the first and second draught). Sheet piling walls of the first draught are surfaced by welding above the upper part of the brickwork.

Additionally, chambers are surfaced by welding (upper chambers of the front wall, partition walls 1-2 draught, and partition wall 2-3 draught), pipe truss (pipes joining upper chamber of partition wall with the drum), and pipe deflection (e.g. deflection of the window for the burner). What is more, surface by welding can also cover an area around the nozzles of the secondary air.

3. Technology of surfacing by welding

A development of materials engineering, electronics, electrical engineering enables surfacing by welding and thermal spraying of elements made from all kinds of known structural materials, even glass and wood. It can be made not only by hand, half-automatic, automatic but also robotized, both in the workshops and outside [10].

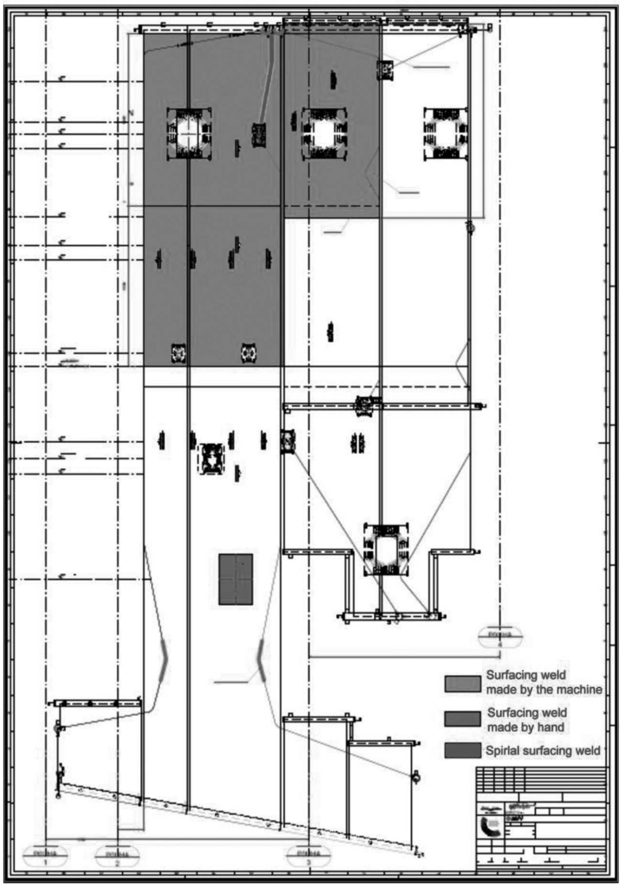

Fig. 4. Sketch showing an area of the Inconel 625 surfacing weld in the boiler used to utilize waste thermally
Source: own study

A progress in the area of welding technologies led into distribution of a few technologies within this area, which is shown in the diagram below.

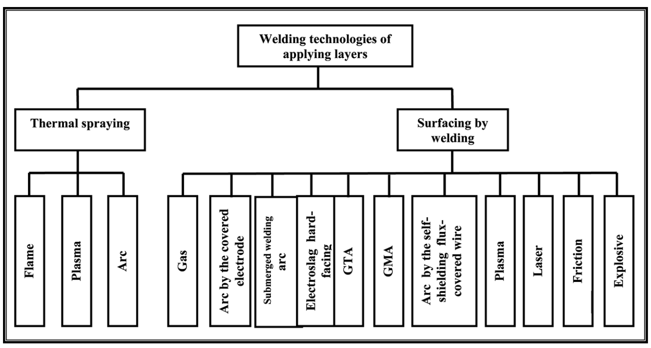

Fig. 5. Basic welding technologies used to apply a surfacing layer [10]

It is necessary to take into account that having so many different welding technologies used to apply layers to choose they cannot be used freely despite being replaceable. In order to choose the most suitable welding process, the following factors should be considered:

– a number and a mass of regenerated or made items,
– a type of the item's material, its condition and weldability,
– a position of an application of a layer depending on the working conditions: abrading type metal-metal, metal-mineral, dynamic load, corrosion, mechanical vibrations, thermal loads, etc,
– a required quality of a layer, its thickness, shape, size and a condition of its surface,
– a type, character, and cost of required filler materials,
– a required efficiency of an applied layer,
– a type of installations used to surface by welding or spraying available in the factory or a cost of a new installation.

The above factors are usually contradictory, which means that a choice of a satisfactory technology can be difficult. The key factors are to guarantee quality and economic.

The following factors have an influence on ensuring a proper quality: type of a process of applying a layer, technology, technological conditions and a filler material.

Costs of filler materials, costs of a device and its amortization, labour costs, costs of an energy and durability of a layer play the major role [10].

The most widespread technology used to apply the Inconel 625 layer on the elements of the boilers is an arc weld surfacing by a consumable electrode in the gaseous shielding – method 135 or 131. The consumable electrode is a solid welding wire of a 1,0÷1,2 mm diameter, which chemical component is close to Inconel 625 alloy.

An influence of the power parameters on the process of surfacing by welding forces to use a direct current and a pulsatory arc, due to this, about 20-30% less heat is put into surfaced by welding material [1].

Applying Inconel 625 layer by the 135 method by the direct pulsatory current enables decreasing an intensity of the transition current in comparison to the surfacing by welding by the direct current with the straight polarity. It allows to obtain lower depths of remelting of the basic material and the lower share of the metal base in the surfacing weld. Additionally, surfacing by welding in the compulsory positions is easier. Due to an appropriate choice of parameters of current impulsing a precise regulation of a metal transfer in an arc takes place. It happens because each current impulse from the end of the wire cause that one drop of a specific parameters of metal falls. Constantly maintained basic current of an arc burning continuously is interrupted by the current impulses with a higher intensity, by which the speed of melting the end of an electrode, forming and falling drops of metal is increased. While surfacing by welding a basic current intensity is higher than a transition current, which means that the electrode is melting with a greater speed in the spraying method [10].

Aiming at getting a layer of a possible the lowest content of iron on the surface led to searching a technology characterised by the low linear energy and a slight heat put into a surfaced by welding element. CMT technology fulfils above requirements.

CMT abbreviation comes from Cold Metal Transfer, and describes the MIG/MAG method, where an amount of heat put into is lower than in the traditional method of surfacing by welding by the pulsatory direct current. CMT technology refers to use a short-circuit arc with a completely new way of detaching a drop of metal from the wire.

In the traditional short-circuit GMA arc, metal is transferred from a consumable electrode into a surfacing weld pool only when a melted end of a wire is close to the surface of the surfacing weld pool. In the CMT method, at the moment of an arc burning, the wire is moved into a surfaced by welding material (Fig. 6 A). When a filler metal is dipped into the surfacing weld pool the arc is blown out (Fig. 6 B). Then, a motion of the wire is reversed, the wire is pulled away, and motion supports a moving metal (Fig. 6 C). Next, metal is drawn out again into a base material and the whole process starts again (Fig. 6 D).

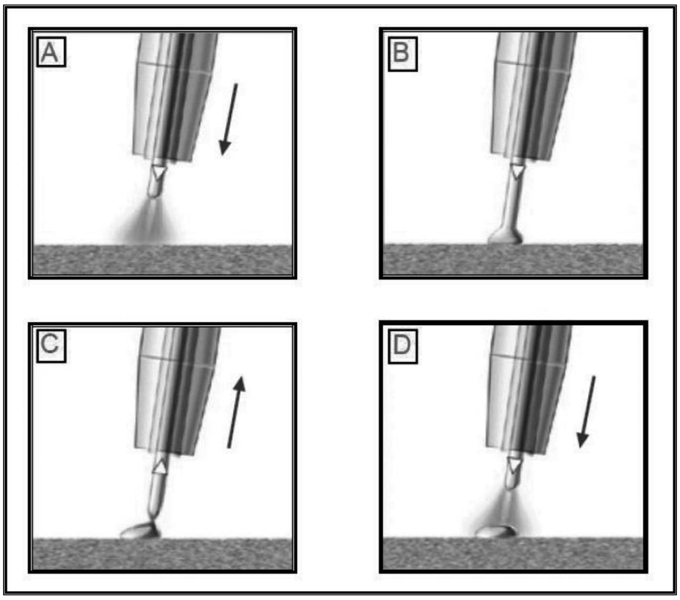

Fig. 6. A process of CMT method of surfacing by welding
Source: www.fronius.com

Surfacing by welding is made by the machines in most cases on the panels of gas-tight walls. Before starting surfacing by welding a panel of gas-tight wall is welded into a specially designed frame. It is made in order to prevent bending the panel during surfacing by welding while putting the heat. The process of surfacing by welding is made vertically from the top to the bottom (PG position).

Technology of surfacing by welding requires a continuous cooling of a surfaced by welding element. The process of cooling takes place by the flow of a cooling liquid (water) through the pipes of sheet pile walls. It is made in order to reduce an excessive growth of a temperature of the surfaced by welding element. It results in an increase of mixing a surfacing weld with a base material, which in turn increases a content of iron on the surface of the surfacing weld. Additionally, due to the cooling process, a deformation effect due to a welding shrinkage is decreased.

After finishing surfacing by welding and removing a panel from the frame it is vital to remove thermal deformations. Bent panel is being straightened, which is made by a special press or heated by the burner, or both.

Making a protective layer of the walls is making singular beads, which overlapping each other cover the whole surface of a given element. There are two techniques single and two-pass surfacing. The idea of each is presented in the pictures 7 and 8.

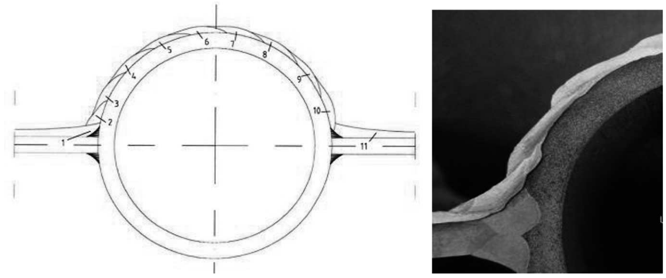

Fig. 7. Single-pass surfacing
Source: *Marketing materials of Uhlig GmbH company*

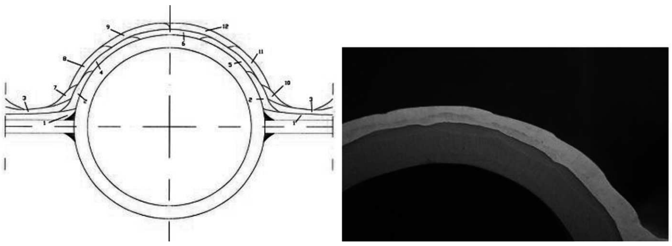

Fig. 8. Two-pass surfacing
Source: *Marketing materials of Uhlig GmbH company*

Single-pass surfacing (Fig. 7) means surfacing by welding by mutually overlapping beads which make a single surfacing layer. Overlapping of beads is necessary, as it is vital to get a surfacing layer which continuously covers a base material.

It is vital that a surfacing weld, which is made by a single-pass surfacing, fulfils the requirements of a minimal thickness of the surfacing layer not less than 2 mm. Additionally, the above technique should fulfil the requirement of 50% of overlapping of beads (Fig. 9). It means that each bead is overlapped in half by another bead. Furthermore, to make a weld bead cross-section we receive two layers of a surfacing weld.

A necessity to obtain a 50% condition of overlapping beads results directly from getting a minimum thickness of a surfacing weld not less than 2 mm. Thickness of a singular bead is not homogeneous in the weld bead cross-section. Simply speaking, the thickest area is around the middle axis, and lowering to the edges. If the thickness of a singular bead does not exceed 2 mm in the weld bead cross-section, than it is necessary to overlap the beads at least 50% on each other.

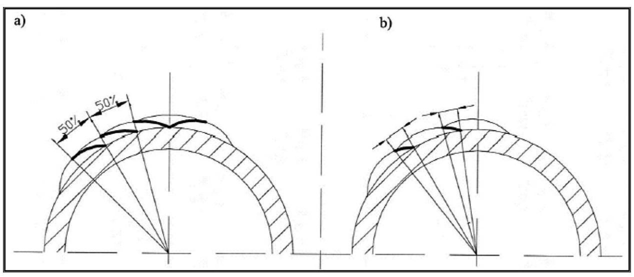

Fig. 9. Single-pass surfacing – overlapping beads
Source: own study

Two-pass surfacing (Fig. 8) takes place in two stages. In the first stage a surfaced by welding material is covered by slightly overlapping beads. A thickness of the first layer is about 1 mm, but not less than 1 mm in the second stage, the second layer of beads is put. The beads are also slightly overlapping on each other on the second layer. The thickness of both layers is at least 2 mm in total.

A proper two-pass surfacing requires a possibility to make single beads which thickness ranges between 1 mm to 1,2 mm. Obtaining given values depends on proper settings of welding machines and a supportive equipment. Traditionally, obtained thickness for a single layer starts from 1,5 mm above for the CMT method. It means that in two-pass surfacing a total thickness of two layers is 3 mm and more. It results in the amount of the costs of welding materials which make the major part of the surfacing by welding costs (about 60% of the direct costs). They are also about 1/3 higher than the costs of a surfacing weld of 2 mm thickness or more.

4. Standard quality requirements

PN-EN ISO 15614-7 standard *(Specification and Qualification of the Technology of Welding Metals – Examination of Welding Technologies – Part 7: Surfacing by Welding)* refers to the conditions of undergoing examinations of welding technologies and the scope of qualifications of welding technologies for all types of practical welding operations. PN-EN ISO 15614-7 standard describes the requirements of the samples for tests, and specifies the types and the scope of non-destructive and destructive testing, which all the samples need to undergo together with acceptance criteria.

On the other hand, quality requirements referring to the surfacing welds used on the sheet pile walls of the boiler equipments are collected and published by the German organisation VdTÜV (Verband der Technischen Überwachungs-Vereine). Above requirements are named „Merkblatt zur Durchfuerung und Pruefung von Auftragsschweissungen an Rohrwaenden von Kesselanlagen" number 1166 (translation in English: 'A Manual of Making and Examining Surfacing Welds on the Sheet Pile Walls of the Boilers Equipment'). Due to the lack of standardization of this area in the European Standards (EN) producers of the boilers used to utilize waste thermally use the Merkblatt 1166 as a collection of quality features, which should be fulfilled by the surfacing weld Inconel 625 [13].

It often happens that producers of the boilers extend both quality and quantity requirements presented in the Merkblatt 1166. It means that a scope and an amount of examinations are increased as well as acceptance criteria are exacerbated. It mainly results from the individual experience of the producers gained during exploiting boilers and their production (surfacing by welding)

The basic requirements which must be fulfilled by the surfacing weld according to the Merkblatt 1166 are as follows [13]:

– lack of the surface defects such as piping, end craters and cracks;
– minimal thickness of a surfacing weld is at least 2,00 mm;
– local lacks of fusions not bigger than 50 mm are possible, but cannot exceed an area of 100 cm^2 on each 1 m^2 of the surfacing weld;

– content of iron (Fe) should not exceed a value of 10%.

Because the main reason of using the Inconel 625 surfacing weld is increasing an anti-corrosive resistance of covered gas-tight pipe walls, the key issue is a quality of the surface. The major task of a surfacing weld is not to allow a direct contact between aggressive elements of burnt gasses and the gas-tight walls of the boiler. All the discontinuities of the surfacing weld decrease its protective features. According to the Merkblatt 1166 following surface defects are unacceptable [13]:

– piping meeting the base material (material which is surfaced by welding);
– end craters;
– cracking.

At the same time, it is advisable to remove piping which does not meet the base material. Occurrence of piping, even if they do not directly meet the base material, favours concentration of aggressive factors, which in turn leads to forming the focuses of corrosion, where corrosion processes take place faster than on the other areas of the surfacing weld. Corrosion tests taken in the same atmosphere for different types of materials (including Inconel 625) prove that the presence of ash taken from the incinerating plant considerably fastens the pace of corrosion [7].

End craters due to used technology of surfacing by welding (131/135) are unavoidable. They appear both at the beginning and ending of a surfaced by welding area. It is necessary to remove them because of an increased pace of corrosion. The easiest and often the only method to remove this type of defect is to make transverse beads by the TIG method. Thus, smooth passages into the base material are obtained.

Additional defects which can appear on the surfaces of the surfacing weld are [14-16]:

– chips;
– lack of filling with the material of the surfacing weld;
– an excessive accumulation of a welding material.

Chips can be removed manually by a chisel. It is vital that a material, which was used to make the chisel, does not contain iron in order not to pollute the surfacing weld. In the polluted by iron areas, due to a contact with elements of ferrite steel, corrosion will appear.

Lacks of the material of the surfacing weld are made because of an instability of a process of surfacing by welding and interrupting an application of a welding material. By the single-pass surfacing holes meet the base material. A lack of a surfacing weld in the lack areas of filling need to be removed by the 141 method.

Disturbances in the mechanical operation of the machine used to surfacing by welding can result in appearance of defects such as a local excessive accumulation of the surfacing weld. Inequalities made in this way should be removed by grinding. Possible finishing of grinding surfaces is made manually by 141 method.

The next basic requirement, which need to be fulfilled by a surfacing weld according to the Merkblatt 1166 is a proper minimal thickness equals at least 2mm. At the same time, upper value of thickness is not specified [13]. Analysing the requirements of the producers of boilers it can be observed that a minimal thickness higher or equal to 2,00 mm is strictly kept, while the maximum thickness of the surfacing weld is rather flexible. There are requirements referring to the thickness of the surfacing weld for three different producers of boilers:

a) producer A
   – minimal thickness: 2,00 mm
   – maximum thickness: 3,00 mm
b) producer B
   – minimal thickness: 2,00 mm
   – maximum thickness: 2,70 mm, while accumulation of the surfacing weld more than 3,00 is unacceptable and it is required to remove it by grinding;
c) producer C
   – minimal thickness: 2,00 mm
   – maximum thickness: a lack of upper value.

As it results from the above example, producers B and C present an extreme point of view about the maximum accepted thickness of the surfacing weld. It can result from the fact that required protective features in respect of durability are obtained for 2,00 thickness. The reasons for describing upper values of thickness of the surfacing weld are as follows:

a) reducing an excessive growth of the mass of surfaced by welding elements;
b) an excessive thickness of the surfacing weld can result from the poor quality of the previous layers of the surfacing weld;
c) reducing an amount of heat put into and deformation related to it due to the welding shrinkage.

Reducing an excessive growth of the mass is important due to the static calculations of the construction supporting the boiler. The growth of one square metre mass of surfaced by welding sheet pile wall depending on the thickness of a surfacing layer is depicted on the diagram below (Fig. 10)

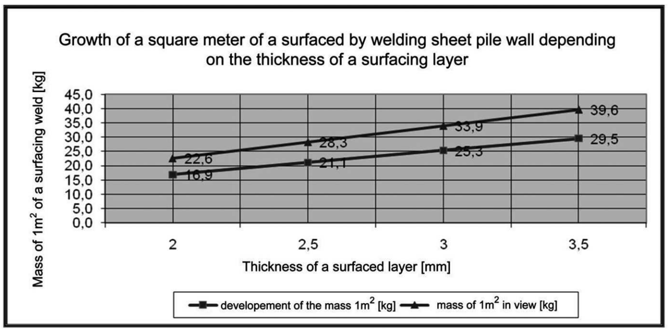

Fig. 10. Growth of a square meter of a surfaced by welding sheet pile wall depending on the thickness of a surfacing layer
Source: own study

Assuming that the size of surfaced by welding areas of sheet pile walls is 400 m^2 a growth of the mass of the surface weld made by the change of the thickness of its layer is presented in the picture 11.

It results from an analysis presented in the diagram underneath that the mass of the boiler's elements increased for around 9 tonnes for the minimal thickness of the surfacing weld 2 mm. Each growth of the surfacing weld thickness of every 0,5 mm causes an increase of the mass of 2,26 tonnes. It means that 3 mm thick surfacing layer weights 4,5 tonnes more than 2 mm thick. These values are vital while designing the boiler and its supportive construction.

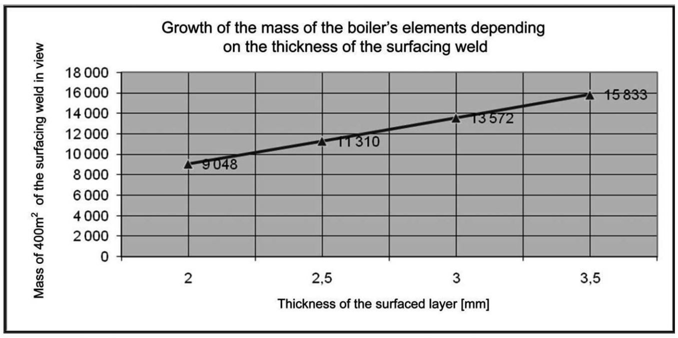

Fig. 11. Growth of the mass of the boiler's elements depending on the thickness of the surfacing weld
Source: own study

The next reason for describing the upper values of the thickness of the surfacing weld is an assumption that an excessive thickness of the surfacing weld means that the previous surfacing layers were of a poor quality. It is connected with the maximum content of iron in the surfacing weld. According to the Merkblatt 1166 a content of iron in the surfacing weld cannot be higher than 10% [13]. It can happen that due to some mistakes while surfacing by welding (e.g. inefficient cooling of the pipes, too high linear energy, etc.) the surfacing weld does not fulfil the condition of a maximum content of iron. In such situation a faulty surfacing weld should be ground and make it once more time. However, it requires an additional work which is grinding. In this case, a contractor in order to hide insufficient quality of the surfacing weld can decide to make only additional surfacing layer. The above situation often happens in cases of a manual surfacing by welding, where it is more difficult to fulfil a condition of a content of iron.

An indirect reason for reducing a maximum thickness of the surfacing weld is decreasing an amount of heat put into, and deformation caused by the welding shrinkage connected with it. Thicker surfacing weld both in single and two-pass surfacing means bigger amount of heat put into the panel of sheet pile wall, and furthermore causes greater deformations. Occurred deformations are as following:
– lack of the flatness of the surface of the panel;
– lack of rectilinearity of extreme edges of the panel;
– lack of a proper distance between the axes of particular pipes of the panel (so called pitch).

Above deformations exceeding possible acceptable values make a proper installation of panels in the sheet pile wall of the boiler difficult or sometimes even impossible.

Among the basic requirements according to the Merkblatt 1166, which the surfacing weld must fulfill, is the condition of a proper fusion of the surfacing weld into the base material. Acceptable situation is a lack of fusion not bigger than 50 mm, and its area cannot be bigger than 100 cm^2 on every 1m^2 of the surfacing weld [13]. Testing is taken by ultrasonic testing method (UT), and its scope covers at least one testing point on 1m^2. In practice, a lack of fusion smaller than 50 mm rarely happens for properly chosen welding parameters. Analyzing quality requirements of the boilers' producers a requirement of control according to the Merkblatt 1166 rarely appears. Often, a control of a proper fusion, is reduced only to test samples made by the welders before starting operating. It is also connected with a rather troublesome requirement of a proper preparation of the surface for ultrasonic testing UT: grinding the surface of the surfacing weld for ensuring an adequate coupling.

The last of the described conditions presented in the Merkblatt 1166 is a requirement of an iron content (Fe) which is not exceeding the value of 10% [13]. Additionally, a chance to make this arrangement stickler is possible if the customers and installers who are making surfacing by welding services wish to do so.

5. Additional requirements

A linear energy of welding is one of the most important factors which decides about a content of iron in the surfacing weld. It is required to reduce an energy of surfacing by welding in order not to exceed an acceptable amount of Fe. According to the tests, obtaining a surfacing weld with a proper content of iron (7% Fe), and an appropriate fusion are conditioned by surfacing by welding with a linear energy which is not exceeding the value of 3kJ/cm [1].

Introducing CMT technology allowed to make surfacing welds with a lower content of iron in comparison to the traditional methods 131/135. It is strictly connected with a smaller amount of heat put into surfaced by welding material in CMT method.

An influence of iron in the surfacing welds on their expected durability is controversial. On one hand, laboratory tests show, that nickel based alloys (inter alia Inconel 625) by increasing a content of iron become less resistant to corrosion. It results from the fact that surfacing welds with Fe content up to 10% are fine in the corrosive environment, while exceeding the value of 10% can result making iron oxides Fe_2O_3o on the surface of the surfacing weld with a considerably lower adhesion to the base than chromium oxides. It can cause a considerably faster use of the surfacing weld in the corrosive-erosive conditions [1].

On the other hand, there are surfacing welds with a content of iron up to 30% made directly in the boilers, which despite many years of operation are still in a very good condition. What is more, there are boilers with surfaced by welding elements with a content of iron less than 5% where reparation is necessary after a couple of years due to an excessive corrosion [11].

It shows that there are other factors than a content of iron which have an influence on the resistance to corrosion. Specialists who deal with corrosive effects in the boilers claim that gained experience allow to form certain conclusions. They are as follows: heat flux thickness influences on the corrosive resistance taking into account a technology of surfacing by welding and a visual appearance of the surfacing weld. It is considered that there is a relationship between a visual appearance of the surfacing weld and corrosion.

Picture 12 presents the results of many years of tests done in the Danish incinerate plant [11]. The results are as follows:
a) two-pass surfacing is more resistant to corrosion than single-pass surfacing with a 50% overlapping of layers;
b) spiral surfacing welds are more resistant to corrosion than surfacing welds made vertically from the top to the bottom (PG position);

c) a content of iron in the surfacing weld is not a decisive parameter in case of comparing singular pipes spirally surfaced by welding (Inconel 626, a content of iron more than 6%) with surfacing welds made in PG position (Alloy 50, Inconel 625 and 686, a content of iron less than 5%).

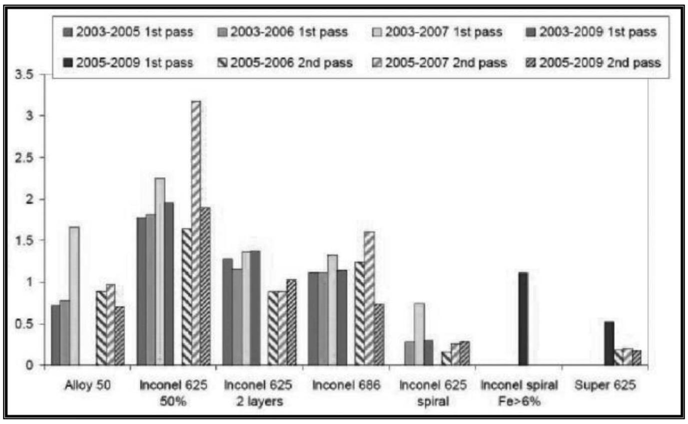

Fig. 12. Degradation of the protective layers (loss of the material in mm) made from 50, 625, 686 alloy and from the material made from Super 625 alloy [11]

Used technology of surfacing by welding relies on covering the surface of a gas sheet pile wall by the Inconel 625 alloy by the beads put one after the other. In practice, it is impossible to make a surfacing weld with a perfectly smooth surface. A surface of the surfacing weld can be additionally smoothed by making fusion using TIG head. However, in practice, it is very expansive, thus used only in case of a spiral surfacing by welding of singular pipes.

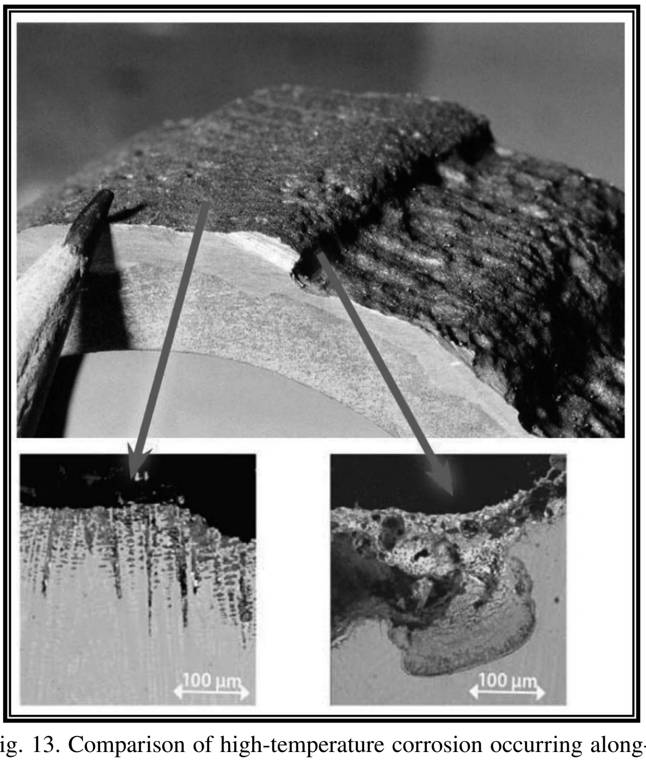

Fig. 13. Comparison of high-temperature corrosion occurring alongside dendrites and pits as a result of melted chlorines [11]

In most cases, the surfacing weld is mostly attacked by the corrosion along the boundaries of beads, where the surfacing layer is the thinnest and where the heat-affected zone (HAZ) appears. Additionally, a pace of corrosion in the above areas is fastened due to an appearance of the thickness of the heat flux. It gains the highest values along the beads' boundaries. It causes a thermophoresis effect in which corrosive substances are transferred into the surfacing weld. The thicker the flux of heat is, the bigger thermal diffusion is, which particularly attacks the least resistant to corrosion heat-affected zones alongside beads' boundaries [11] and other waste phenomena [17-19]. Corrosion alongside beads' boundaries is depicted in the picture 13.

6. Summary

It can be observed that despite a lack of a technological possibility to make a surfacing weld by the CMT method with a perfectly smooth surface, we should aim at minimizing all kind of irregularities of the surface. Practice proves that surfacing welds with smaller amount of the surface irregularities show greater resistance to corrosion. On the other hand, standards including the Merkblatt 1166, do not provide acceptance criteria for an appearance of the surfacing weld. Referring to the condition of the surface, the Merkblatt 1166 provides criteria only for craters, scratches and piping without specifying any other kind of irregularities [13]. There is some kind of freedom about the requirements specified by the customer, thus it is advisable to settle all the expectations for an appearance of the surface between the parties before starting working. Therefore, it is helpful to make a reference panel which becomes a reference for the production elements.

Additional condition given in the technical specifications refers to the way of putting the beads of the surfacing weld. In practice, there are two ways of putting beads on the sheet pile walls of an evaporator i.e. single-pass surfacing and two-pass surfacing on the pipes of the heaters are used by the Inconel 625 method (thickness of the surfacing layer from 1 mm). Preferable, and often the only permissible by the customer is two-pass surfacing, which according to the widely spread opinion shows greater resistance to corrosion [11].

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Received: 20 September 2014.