WELDING TECHNOLOGIES

1. THE TECHNOLOGIES OF THERMAL CUTTING

The processes of oxyfuel and plasma cutting are used in approx. 90% of thermal cutting processes used in industry. The distinguishing characteristics of oxyfuel method is its low costs, as the classic burners allow to cut about 300 mm deep and the special burners allow to cut the steel of even over 2000 mm deep. The disadvantages of oxyfuel method are low accuracy of cutting, large heat affected area, lack of possibility to cut stainless steel, aluminium and copper alloys. Plasma torches allow to cut metal alloys which cannot be cut with oxygen torches. The comparison made in shipbuilding industry indicates that approximately 70% of cut elements are up to 30mm thick and therefore they might be cut with plasma burners.

Tab. 1.1. The comparison of technological, technical and economical characteristics of selected cutting processes [1]

Characteristic of the process		Oxygene cutting		Arc-air cutting of area	Plasma cutting		Laser cutting	Water cutting
		A	P		T	P		
Ability to cut sheet metal of thickness	<5 mm	□	□	Φ, □	○	○	○	○
	5÷25 mm	○	□	○	○	○	□, Φ	○
	25÷100 mm	○	□	□	○	□	Φ	○
	>100 mm	Φ	○	Φ	Φ	Φ	Φ	○
The ability to cut metal sheets with a surface covered with rust and descaled surfaces		□	□	○	□	□	□, Φ	○
Quality of cutting		□	□	□, Φ	□	□	○	□
Deformation		□	□	□	□	□	○	○
Speed of cutting		□	□	□, Φ	○	○	○	□
Ability to gauge		○	○	○	○	○	○	○
Piercing ability		○	□		○	○	□	□, Φ
Material	C-Mn steels	○	○	□	○	○	○	○

being cut	Cr-Ni steels	Φ	Φ	Φ, □	○	○	○	○
	aluminium	Φ	Φ	Φ, □	○	○	○	○
	copper	Φ	Φ	Φ, □	○	○	○	○
	titanium	Φ	Φ	Φ, □	○	○	○	○
		○	○	○	□	○	□	□

○- recommended, □- possibile to use, Φ- not recommended

In case when high quality of cutting or cutting the materials which do not conduct electricity is required water cutting and laser cutting are used. Each of these methods has recommended scopes of application (Tab.1.1).

1.1 Oxygen cutting

The method of oxygen cutting consists in heat the material over the ignition temperature, which triggers highly exothermic reactions of oxidation of the material. The ignition temperature must be lower than the melting point, which limits the usage of oxygen cutting only to iron and titanium alloys. The ignition temperature depends on the contents of carbon in cut steel fig. 1.1. Steels with contents of carbon up to 0,45% might be cut without heating. Liquid metal and products of oxidation

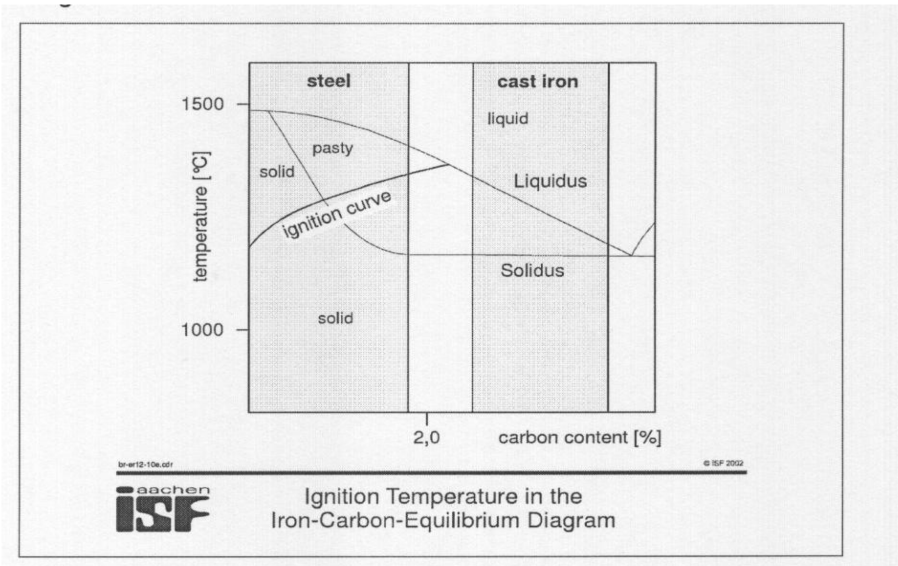

Fig.1.1 Dependence of ignition temperature on coal content [2]

are removed by the stream of gases from the kerf. The maximum contents of other alloying elements are listed in Tab. 1.2 [2]. The negative impact of alloying elements is that they constrict

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Project co-financed by the European Union under the European Social Fund

the oxidation of steel, create oxides with high melting point, increase hardenability of steel and cause cracks. For cutting-manual and machine burners are used. The burner for oxygen cutting allows to heat the area of cut steel up to the ignition temperature and apply additional cutting oxygen to the heated area. For cutting- the high-purity oxygen (over 99,5%) should be used.

Tab. 1.2 The maximum contents of alloying elements in cut steels [2]

Element	Maximum contents, %
C	1.6
Si	2.5% for C_{max}=0.2%
Mn	13% for C_{max}=1.3%
Cr	1.5%
W	10% and maximum contents Cr=5%, Ni=0.2%, C=0.8%
Ni	7% or 35% for C_{max}=0.3%
Cu	0.7%
Mo	0.8% with larger contents of W, Cr i C cannot be cut

For cutting the materials portal machines with sliding gates are used, to which various heads can be attached, i.e. for plasma cutting, ink marking, drilling, water cutting or oxygen cutting.

1.2. Laser cutting

The power density of laser beam while cutting or making holes is within the range of 10^4-10^6 W/mm^2 [1]. The advantages of laser cutting are narrow kerf, high quality of cut edges, narrow heat affected zone. The accompanying gas removes liquid metal from the kerf and protects the optical system from condensation of vapor of cut metal and from the spatters. The accompanying gases used in laser cutting are air, nitrogen, argon and oxygen. By using the oxygen and air, the speed of cutting iron alloys increases as a result of the appearance of exothermic reactions of iron oxidation.

1.3. Water cutting

The speed of a stream of water is up to three speeds of sound. The most often used abrasive is garnet with grain of 80 mesh. The material being cut remains on a table covered with grate. Inside the table there is a thick layer of water, which is supposed to absorb the energy of the stream of water. Due to the relatively small head reject during its work and its low weight the 3D cut with five axial machines is possible.

1.4. Arc-air cutting with graphite electrode

The applied electrode has copper coating which provides good electrical contact. The air compressed to pressure 0.5-0.7 MPa which blows up the liquid metal and oxides is fed to the arc-air grip. The method is used for cutting steel and removing defects in castings.

1.5. Plasma cutting

The source of heat used during plasma cutting is concentrated plasma arc. The arc is burning between nonconsumable electrode placed in the burner and the object being cut. The concentration of the arc is connected to the proper molding of the gas nozzle and with the influence of Lorentz force on electricity carriers. Fig. 1.2 presents the comparison of different cutting methods.

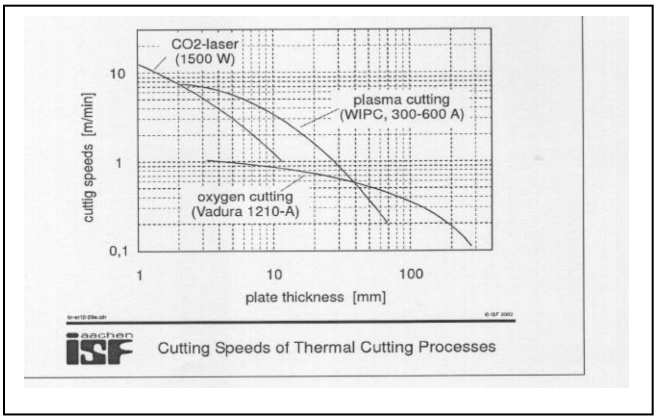

Fig.1.2. Comparison of cutting methods

1.6. The practical part

1. Acquainting with the construction of devices used for oxygen cutting, plasma cutting and arc cutting.
2. Evaluation of impact of the parameters of plasma cutting on the quality of the cutting.
3. Comparison of the quality of water cutting and plasma cutting.
4. Performing samples of oxygen cutting, plasma cutting and arc cutting.

1.7 . Bibliography

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2. Technologies of hardfacing

The beneficial method of increasing usage properties of surface is to put coatings with the use of hardfacing method. The distinguishing feature of hardfacing is partial melting of the base metal and formation of a transition zone, the chemical composition of which is intermediate between chemical composition of the base metal and the composition of the material used for the forming of the coating. The purpose of hardfacing might be to regenerate the used material, which is to reinstate the shape and the performance. In some cases it is used during the stage of production to provide the surface layer with required performance. The condition of the surface area affects the durability of the whole element, which is exposed to abrasive, erosive wear or corrosion. The purpose of hardfacing might be also to creating the buffer layer, which is intermediate between the base metal and the layer resistant to specific type of wear. In most cases a small admixture of the base material in weld is beneficial. The base material in heat affected zone goes through microstructural changes, the scope of which depends on the reached temperature, heating period and the speed of temperature changes. The further away from the fused zone the smaller the scope of changes. The performance of the harfacing depends on the material used to creating the coating, base material and technology of hardfacing. After hardfacing is completed, the element which underwent this process is left with internal welding stresses which overlap with stresses resulting from the working of the element. The hardfaced coatings which are highly resistant to wear might contain cracks and cannot be exploited in conditions allowing propagation of cracks.

Tab. 1 presents the comparison of hardfacing methods, which differ in thickness of formed coating, efficiency and dilution [1].

2.1. Gas hardfacing

Project co-financed by the European Union under the European Social Fund

The source of heat is a gas burner. Additional material might be in the form of powder, a bar, flux-cored wire or a peg device. The materials used for hardfacing are metal alloys or cermets. The flammable gases are most often acetylen, propane, mixtures of hydrocarbons (MAPP), gases on the base of propylene.

Tab. 2.1. Characteristics of hardfacing processes [1]

Hardfacing method	Minimal thickness of the coating, mm	Efficiency of hardfacing, kg/h	Dilution, %
Gas	0.5	1	Up to15
Flame-powder	0.1	0.2÷1	-
Coated electrode	3	1÷4	15÷30
Nonconsumable electrode in gas shield (TIG)	1.5	2	5÷10
Plasma, with transferred arc	2	10	2÷10
Consumable electrode with gas shield	2	3÷6	15÷30
Flux-cored wire	2	3÷6	15÷30
Submeged, wire	3	10÷30	15÷30
Submerged, tape	4	10÷40	10÷25
Electro-slag	4	15÷35	5÷20

Before hardfacing the material must be properly prepared to obtain clean surface and alternatively the keyway to accommodate weld. Due to the risk of cracking initial heating of hardfaced elements might be necessary and after hardfacing cooling at proper speed or later thermal treatment should be applied.

In flame-powder hardfacing method powder material is used, which is being sucked to the stream of oxygen and put with it to the flame. The powder melts in the flame and its particles are transported in a stream of the products of burning flammable gases. Gas hardfacing with cermets in form of a wire or a bar is used for regenerating of drills, excavator buckets, edges of screw conveyors.

2.2. Hardfacing with shielded electrode

In hardfacing with shielded electrode the arc is burning between the electrode and the hardfaced object. The heat of electrical arc melts the end of the electrode and partially melts the foundation metal. The gaseous envelope is provided with gas products of decomposition of the coating of the electrode. The wire or the bar or alternatively a pipe with a powder core is the core of the electrode. Ignition of the arc is a short circuit. In place of ignition, pores and gas bladders might appear, therefore, this place should be later covered with hardfacing weld. The arc temperature is approximately 5000^{0}C. Expected performance is achieved in most cases at second or third layer of hardfacing weld. The disadvantage of the method is low efficiency of manual hardfacing. The advantage is the possibility to hardface any elements and to make the layers outdoor.

Powder electrodes allow to make hardfacing welds, having a wide scope of chemical composition. A beneficial effect of high electrical resistance of the powder is a considerable increase of hardfacing efficiency.

2.3. Arc welding with consumable electrode in gas shield

Arc welding with consumable electrode in gas shield (GMA, Gas Metal Arc) is to melt the electrode with heat of the electric arc, which is glowing between the electrode and the hardfaced material in gaseous envelope. Simultaneously, partial melting of the foundation metal occurs. The hardfacing weld is produced from melted welding electrode with melted foundation material. Applied shield gas might be a neutral gas (MIG method, Metal Active Gas) or an active gas (MAG method, Metal Active Gas).The consumable electrode might be solid wire or powder wire. Applied neutral gases are argon, helium and mixtures of them. Active gases are mixtures containing CO_2, O_2, H_2, N_2, NO and CO_2 or N_2 applied separately.

2.4 Hardfacing with TIG method

The source of heat in hardfacing with TIG method is electrical arc, which is glowing between the end of nonconsumable electrode and the hardfaced element in the neutral gas. Shield gases applied in the method are Ar, He and mixtures of them. In some cases mixtures containing H_2 and N_2 are used, which increases efficiency of hardfacing. Protective gas protects the nonconsumable electrode and weld pool and has an influence on the voltage of the arch and the shape of the bead. Important characteristics of the gases influencing the hardfacing process are: density, heat transfer and ionization energy. The arc glowing in helium has considerably larger energy in comparison to the arc in the cover of argon. Helium shield is used for hardfacing thick elements with high speed and for hardfacing the substrates with good heat transfer. The advantage of TIG method is high energy density, low volume of weld pool, narrow heat affected zone.

Nonconsumable electrodes are made of tungsten, most often from a tungsten alloy containing the admixture of thorium, lanthanum, zirconium, cerium or yttrium. Hardfacing with pulsating electric current allows for limiting the amount of heat provided during hardfacing as well as lowering the amount of foundation material in hardfacing weld. Alternating current (pulsating) allows for cathodic cleaning, which removes oxides from the surface of aluminum and magnesium alloys at the stage of voltage cycle when the electrode is at positive potential in relation to the hardfaced material. The volume- current characteristics of the source of the current should be fiercely descending.

The material used for hardfacing might be a solid wire, a powder wire, a solid bar, a powder bar, a spun rod, powder or tape or pile alternatively. Hardfacing weld might be made with method to right or to left. Method to left allows for achieving higher efficiency of hardfacing and lower depth of melting of the foundation in comparison with the method to right.

2.5. Plasma hardfacing

Plasma torch is a continuation of TIG method. Plasma torches might be divided into two groups: burners with non-transferred arc and with transferred discharge. In torch with non-transferred arc the discharge is glowing between the nonconsumable electrode and plasma nozzle. In the transferred arc, the discharge is glowing between the nonconsumable electrode and the hardfaced object. In torch with non-transferred arc a stream of plasma with considerable speed and temperature is produced. Such a solution is used in plasma spraying. Torches with transferred arc are generally used in welding and hardfacing. The source of heat in plasma hardfacing is concentrated electric arc burning between the infusible electrode and the hardfaced object. Narrowing of the plasma arc is produced by applying proper plasma nozzle. It is estimated that the temperature of plasma is 16000 ^{0}C.

2.6. The practical part

1. Acquainting with the construction of the devices for plasma hardfacing, TIG hardfacing and gas hardfacing.
2. Evaluating of pad welding of particular steels.
3. Production of the coatings hardfaced with plasma hardfacing, TIG hardfacing and gas hardfacing.
4. Visual evaluation of the hardfaced coatings.

2.7. Bibliography

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3. The technology of thermal spraying

The processes of thermal spraying are divided into three groups depending on applied source of heat: the technology of flame spraying, using electric arc and the technologies using plasma arc. Providing thermal energy to the material which is in a form of powder, a wire or a bar results in melting or partial melting of its particles. The particles are then accelerated in a stream of gases which are the products of burning, in a stream of plasma or with the aid of compressed gases. During spraying melting the foundation material does not occur and the coating being sprayed is connected with the substrate by mechanical conjunction, adhesively or in exceptional cases metalurgically. Very important advantage of thermal spraying is the diversity of the materials which might be used for the production of the coatings. The temperature of sprayed elements is from 423 K to the temperature close to melting point, depending on the type of technology and the technique of spraying. The amount of heat brought to the foundation during spraying is considerably smaller than the heat brought during hardfacing. The coating sprayed with metal alloy is made of metallic particles which are separated irregularly with oxides and pores, produced as a result of not complete filling of all irregularities with particles.

Fig. 3.1 presents ranges of temperature of gases and speeds of sprayed particles in particular processes of spraying

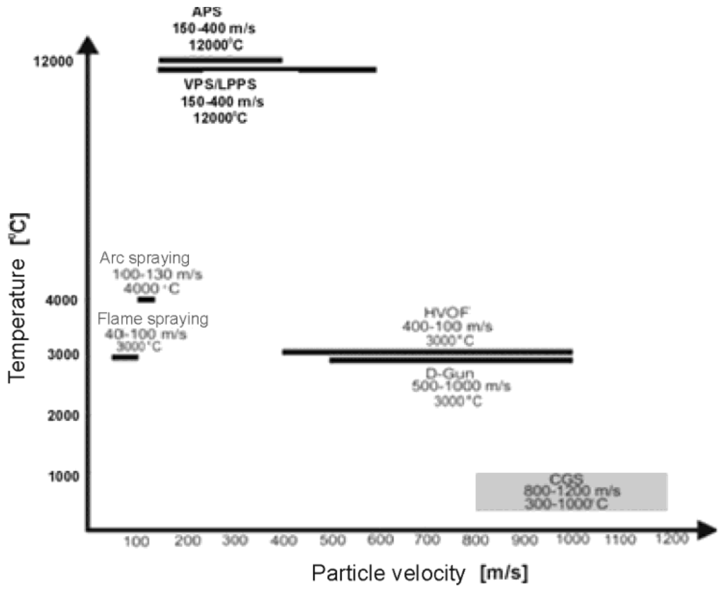

Fig.3. 1. Typical temperature ranges and speeds of particles in particular methods of spraying [1]

Coatings sprayed thermally might be made not only on metal substrates but also on non-metal materials such as wood, glass, porcelain, ceramics and even textiles and paper. The purpose of initial preparing of the foundation is to remove from the surface being sprayed rust, humidity, oil, etc. Initial preparing also includes decreasing the dimensions of the element to save some space for the coating or, if necessary, to prepare a change of shape of the surface to easily product a coating of equal thickness. Very beneficial processing is abrasive blasting with loose abrasive, for instance corundum, which makes the surface properly rough.

The methods of flame spraying are divided into two groups depending on the speed of particles: spraying with subsonic speed and spraying with supersonic speed.

3.1. Flame spraying with subsonic speed

The method uses the heat of combustion gas (usually acetylene or propane) in oxygen in order to melt the coating of the material. The melted particles are accelerated in a stream of gases being combustion products or in the stream of a compressed air. The coating may be formed of metallic, ceramic, cermet and plastic materials. The materials are introduced to the burner in the form of powder, a rod or wire.

Gas temperature has a significant influence on the properties of the produced coatings, ceramic coatings are produced by plasma spraying mainly while materials that are subject to transformations at high temperatures, for example, cermets, are sprayed by other methods characterized by a lower process temperature. The influence of the particle velocity on the properties of the coating results from the fact of the flattening of the particles striking the substrate and cooling of high speed.

Flammable gases used in spray burners in subsonic spraying are acetylene, propane, propylene, hydrogen, natural gas, methane or coke oven gas [2]. The most commonly used combustible gas is acetylene, its flame temperature is approx. 3100 ° C. Propane-butane is used for spraying of metals with a low melting point, for example zinc, aluminum, lead. The powder material may be fed by gravity or from the external powder feeder in a stream of carrier gas (argon or nitrogen). Average particle size of the powders used is in the range 5-100 microns. Spraying distance is 120-250 mm.

Diagram of the flame spraying process of the powder is shown in Fig. 3.2.

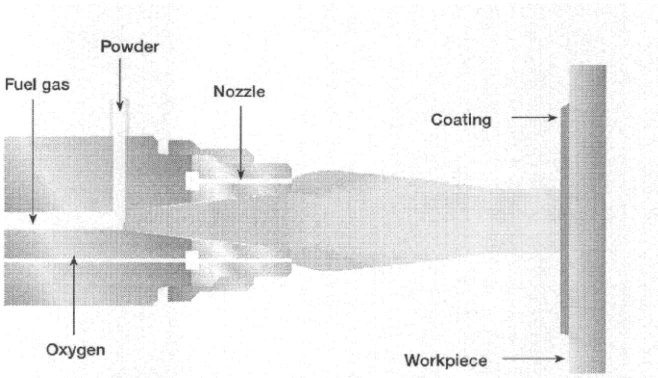

Fig. 3.2. Scheme of the process of flame-powder spraying [3]

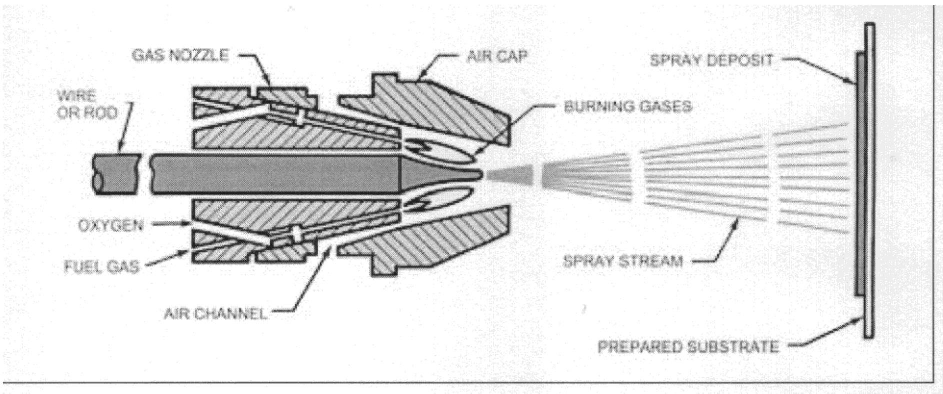

Fig. 3.3. Scheme of the process of flame spraying from the wire [4]

3.2. The arc spraying method

The arc spraying is melting of two metal solid or powder wires with the heat of electric arc of temperature up to 6100 K, which is glowing between their ends. Both of the wires are put with constant and equal speed. The stream of compressed air of high flow rate tears melted material out of the wire, atomizes it into tiny particles and highly accelerates. The burner for arc spraying is presented in Fig. 3.4.

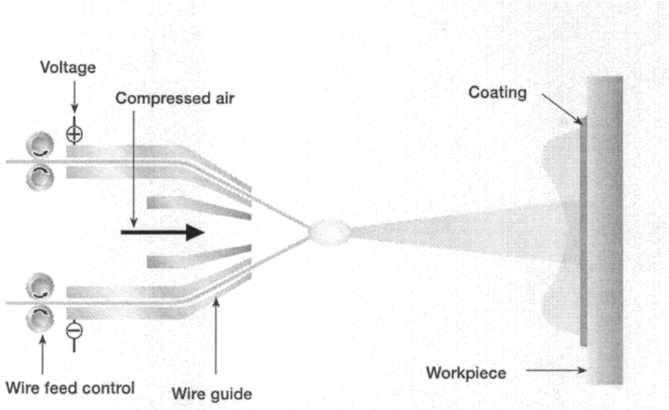

Fig. 3.4.Scheme of the process of arc spraying [3]

3.3. The practical part

1. Acquainting with the devices for flame- powder spraying and from flame spraying from the wire
2. Making the coatings sprayed with flame-powder method.
3. Comparing the characteristics of coatings sprayed with arch method, plasma method and flame method from the wire.

3.4. Bibliography

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