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MULTI-COMPONENT GAS MIXTURES FOR CONSTRUCTION AND SPECIAL STEEL ARC WELDING AND INFLUENCE ON FFR (FUME FORMATION RATE)

VIŠE KOMPONENTNE GASNE MEŠAVINE ZA ELEKTRO-LUČNO ZAVARIVANJE KONSTRUKCIJSKIH I SPECIALNIH ČELIKA I NJIHOV UTICAJ NA KOLIČINU I HEMIJSKI SASTAV DIMNIH GASOVA

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Abstract

MIG / MAG welding with solid or flux cored welding wire and TIG welding are most important arc processes for industrial application. In last period, laser welding become more and more important in industrial welding and cladding applications. Optimum selection of welding process for specific application include more important parameters like productivity, demand quality of weld and influence of welding process to health of welder. With shielding gases is possible to influence on productivity, and quantity of welding fumes. Some welding shielding gases include nitrogen.

Rezime

MIG / MAG zavarivanje sa punom ili punjenom žicom i TIG zavarivanje u praksi su najčešće upotrebljene aplikacije elektrolučnog zavarivanja u industriji. U zadnje vreme i zavarivanje laserom često se upotrebljava u industrijske namene. Izbor procesa zavarivanja za određenu aplikaciju zavisi od više parametara, od kojih među najvažnije spadaju produktivnost, zahtevani kvalitet zavarenog spoja i uticaj procesa zavarivanja na zdravlje zavarivača. Optimizacija zaštitnog gasa za zavarivanje utiče se na produktivnost, količinu i hemijski sastav dimnih gasova. Neki od zaštitnih gasova sadrže određeni deo azota.

1. Introduction

The goal of the joining processes is to cause diverse pieces of material to become a unified whole. In the case of two pieces of metal, when the atoms at the edge of one piece come close enough to the atoms at the edge of another piece for interatomic attraction to develop, the two pieces become one. In theory is this much easy to describe. In real situation basic material include imperfection like surface roughness, fitting imperfections, impurities, chemical and mechanical differences. Welding processes and procedures have been developed to overcome these difficulties by incorporating the use of heat or pressure, or both.

The term arc welding applies to a large, diversified group of welding processes that use an electric arc as the source of heat. Industrial wide used are MIG/MAG welding with solid wire or with flux cored wire, TIG welding and in last decades also laser welding for special welding applications and cladding. The arc is burning between the work piece and the tip of the electrode. The concentrated heat melts base material and welding consumables, resulting in the formation of a weld. Arc welding operation is performed by conducting the welding current through consumable electrodes, which take the form of a wire or rod, or non-consumable electrodes, consisting of tungsten rods. Metal arc processes like GMAW utilize consumable electrodes that combine electrode filler metal with the molten base metal to create the weld. The non-consumable arc process, like GTAW and LBW can generate a weld by melting the base metal only. If filler metal is required in a non-consumable process, it may be add either manually or automatically into the molten weld pool.

Processes GMAW, GTAW and LBW for arc protection are used shielding gas or gas mixture. The selection of the correct shielding gas for a given applications influence to the quality of the finished weld. The criteria used to make the selection includes, but is not restricted to, the following:

- Alloy of wire electrode,
- Desired mechanical properties of the deposited weld metal,
- Material thickness and joint design,
- Material condition – the presence of mill scale, corrosion, resistant coatings, or oil,
- The mode of GMAW metal transfer,
- The welding position,
- Desired penetration profile,
- Desired final weld bead appearance,
- Cost.

Shielded gases we can divided to universal shielding gases, that can be used in wide range of application and special shielding gases, which are created for special application or group of special applications. Typical wide range used shielding gas is inert gas Argon, which can be used for GTAW and LBW applications, for all range of commercial interesting metals if purity of gas is 5.0. It is used for non-alloyed steel, high-alloyed steel, aluminium, magnesium, titanium and their alloys. If we focus on GMAW welding of non-alloyed construction steel, Ar + 18 % CO_2 is universal gas mixture. Special gas mixtures ware developed like multi-component mixtures. Mostly, they are produced with 2 - 4 components, where basic gases are inert gases like Ar and He and add gases are CO_2, O_2, H_2 and N_2. With special shielding gases it is possible to improve productivity, increase welding speed, influence on weld penetration, influence to microstructural components, reduce height of weld bid, decrease work after welding and overall decrease costs of welding process (Figure. 1). More than 80 % of total costs in arc welding processes in industrial environmental are connected to labour, less than 20 % costs are connected to filler material, shielding gas, power.

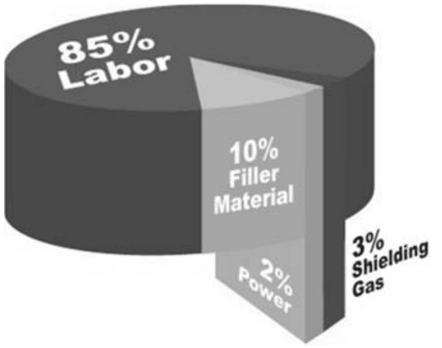


Figure 1. *Costs in GMAW welding process [1]*

Slika 1. *Troškovi u procesu GMAW zavarivanja [1]*

In last time is more and more important, that with special multi-component mixtures we can influence on quantity and chemical composition of fume gases during welding. Quantity of fumes decrease, also quantity of Fe-oxides [2].

1.1 Nitrogen in shielding gases

Nitrogen is not common component in shielding gases for arc welding. Use of nitrogen is in connection to base material or influence to the shape of arc in GTAW welding. Nitrogen influence on microstructural components duplex and superduplex high alloyed steel. Gas mixtures with nitrogen are used for GTAW welding of aluminium and aluminium alloys, GMAW welding of duplex and superduplex high-alloyed steels and for GMAW welding high nitrogen steels (HNS), like Cr20Mn16NiN with low nickel content, where nitrogen alloying improve the strength and corrosion resistance of austenitic steel [3, 4], adding nitrogen to the HNS also improves the ballistic performance of the material. Therefore, the application of HNS as the armour material is receiving a lot of attention in recent years [5]. Escape and accumulation of nitrogen occur during the fusion welding process of HNS. This increases the ferrite content of the weld [6]. In addition, the weld that lacks nitrogen will become the weakness when the structure is impacted, which limits the application of the steel in the defence field.

Most researchers that added N_2 to the shielding gas mainly aims to increase and stabilize the austenite of the weld [7, 8], hardness of the solidified zone [7, 8] and the corrosion resistance of the joint can be enhanced [9]. It is reported by Elmer [9], that the addition of N_2 to the shielding gas can also effectively suppress the formation of pores compared to pure Ar [10].

As shown on Figure.2, when using pure Ar to shielding gas for HNS, the nitrogen of the weld is all derived from the base material and the nitrogen of the molten pool escapes from the lower to the upper. With the application of N_2-containing shielding gas, the direction of nitrogen diffusion is from the surface of the molten pool to the interior.

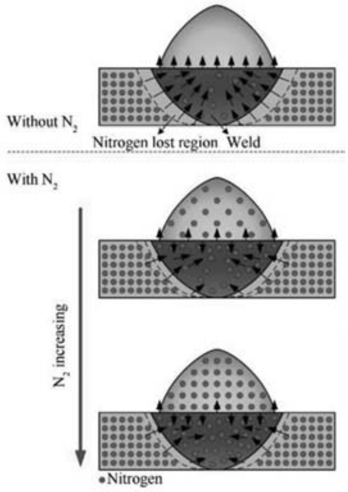


Figure 2. *Schematic presentation of the welding with Ar and Ar+N_2 gas mixture [11]*

Slika 2. *Šematski prikaz zavarivanja gasnom smešom Ar i Ar+N_2 [11]*

1.2. FFR and shielding gases

The development of shielding gases for arc welding applications has been of increasing interest and importance for three main reasons: to improve the productivity of the process, to increase weld integrity and quality, and to reduce the health and safety problems due to fume and particle emissions.

GMAW process has been of great importance for welding constructions all over the world. This fact is related to its high flexibility, which allows the welding of different materials and thicknesses, and to its considerable potential for automation and robotization._The generation of welding fumes during arc welding processes are potentially hazardous to the welder's health. Welding fumes consist of metal oxide particles that can remain suspended in the air and thus, can be inhaled by welders. The chemical composition and particle size of the fume particulates are important parameters in determining the toxicity of welding fumes.

About 90–95 % of the fumes are generated from the filler metal and flux coating/core of consumable electrodes. Since the base metal weld pool is much cooler than the electrode tip, the base metal contributes only a minor amount of the total fumes. The only case when the base metal may be a significant factor of the fume exposure is if the metal or surface residue contains a highly toxic substance (lead, cadmium, etc.). In addition to the welding technique, studies have shown that the fume generation rate is also influenced by the following factors: electric current, arc voltage, wire diameter, shielding gas, welding speed and steady/current pulsed welding mode [12, 13].

The characterization of welding fume depends on consumables and base material. Most dangerous in steel welding are alloying elements. Typically found in welding fume are aluminium, beryllium, cadmium oxides, chromium, copper, fluorides, iron oxide, lead, manganese, molybdenum, nickel, vanadium, and zinc oxides. Each of these elements has harmful effect on human health.

Manganese: Manganese is basic alloying element in non-alloyed construction steels. Inhalation of fumes with high concentrations of manganese and its oxides may bring "metal fume fever".

Chromium: Chromium is an element present in the consumables and base material of stainless steels, heat-resistant steels, some creep-resistant steels, some high nickel alloys, and armour plate.

Chromium can be present in fume in different forms: chromium in metallic form (valence state 0), trivalent form (Cr III) and hexavalent form (Cr VI). Hexavalent chromium is considered as the most hazardous of all forms, and in welding fume it is a suspected human carcinogen [14]. This is consistent with the classification of hexavalent chromium as a human lung carcinogen [15].

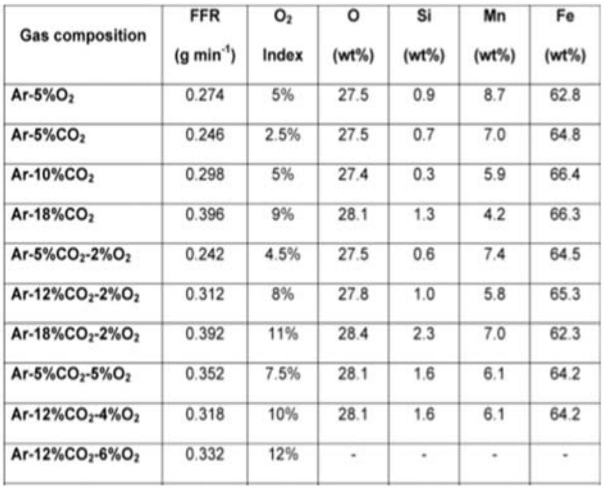
Nickel: Metallic nickel and certain soluble nickel compounds as dust or fume cause sensitization dermatitis and probably produce cancer of the paranasal sinuses and the lung; nickel fume in high concentrations is a respiratory irritant [16].

Aluminium: Long term aluminium exposure is associated with Alzheimer's disease; recent review identified how aluminium may contribute to the formation of Amyloid proteins in the brain, a marker of Alzheimer's disease [17].

More research was done to analyse FFR and fume particle composition in GMAW for plain carbon steel using different shielding gas. According to study of K.R. Carpener [18] which standard Ar+18% CO_2 gas mixture was compared with Ar mixtures with 5% O_2, 5-18% CO_2 Ar, 5-18% CO_2 and 2-5% O_2 gas mixtures on fume box design according to ISO15011-1 [19]. Average particle composition was measured, results are in Table 1.

Table 1. *Shielding gas mixtures used for robotic GMAW, FFR results, O_2 index and average particle composition [18]*

Tabela 1. *Smeše zaštitnih gasova koje se koriste za robotizovan MAG, FFR rezultati, O_2 indeks i prosečni sastav čestica [18]*



Gas composition	FFR (g min^{-1})	O_2 Index	O (wt%)	Si (wt%)	Mn (wt%)	Fe (wt%)
Ar-5%O_2	0.274	5%	27.5	0.9	8.7	62.8
Ar-5%CO_2	0.246	2.5%	27.5	0.7	7.0	64.8
Ar-10%CO_2	0.298	5%	27.4	0.3	5.9	66.4
Ar-18%CO_2	0.396	9%	28.1	1.3	4.2	66.3
Ar-5%CO_2-2%O_2	0.242	4.5%	27.5	0.6	7.4	64.5
Ar-12%CO_2-2%O_2	0.312	8%	27.8	1.0	5.8	65.3
Ar-18%CO_2-2%O_2	0.392	11%	28.4	2.3	7.0	62.3
Ar-5%CO_2-5%O_2	0.352	7.5%	28.1	1.6	6.1	64.2
Ar-12%CO_2-4%O_2	0.318	10%	28.1	1.6	6.1	64.2
Ar-12%CO_2-6%O_2	0.332	12%	-	-	-	-

On Table 1. shows the, that quantity of FFR for mixtures with Ar-CO_2-O_2 chemical composition and same O_2 index grove slower than for Ar-CO_2 shielding gas composition. FFR results are present in Figure 3.

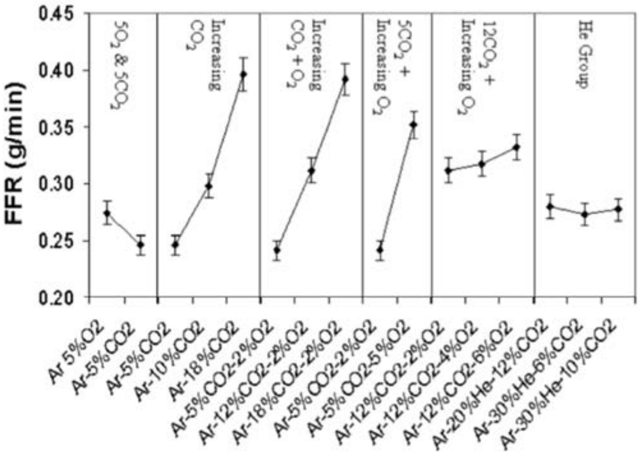


Figure 3. *FFR as a function of shielding gas composition under the same welding conditions. Each region on the graph, groups the shielding gas mixtures according to different variables in the composition [18]*

Slika 3. *FFR kao funkcija sastava zaštitnog gasa pod istim uslovima zavarivanja. Svaki region na grafikonu grupiše smeše zaštitnog gasa prema različitim promenljivim u sastavu [18]*

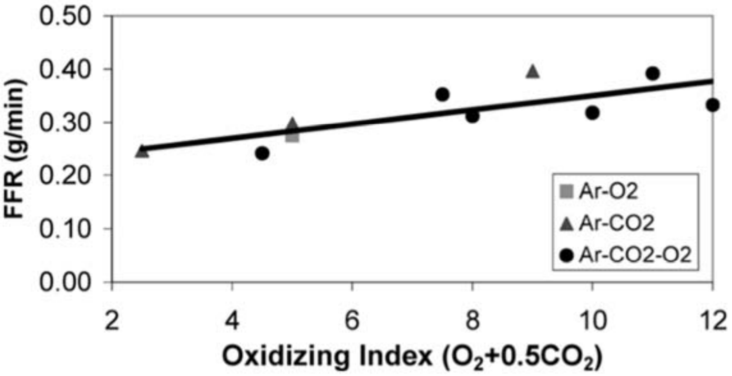


Figure 4. *FFR plotted against oxygen index for the Ar–O_2, Ar–CO_2 and Ar–CO_2–O_2 series [18]*

Slika 4. *FFR prikazan u odnosu na indeks kiseonika za serije Ar–O_2, Ar–CO_2 i Ar–CO_2–O_2 [18]*

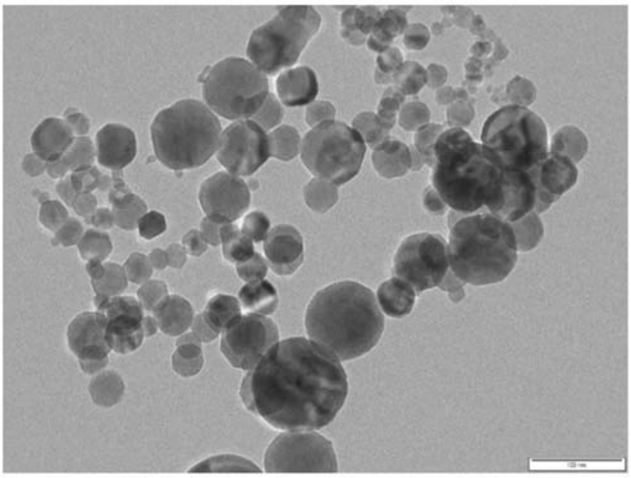


Figure 5. *Typical bright field TEM image at 200K times magnification showing welding fumes with a mixture of particle sizes, with either spherical or faceted morphology and often in chain-like structures (shielding gas: Ar–10 CO_2) [18]*

Slika 5. *Tipična TEM slika svetlog polja na uvećanju od 200K puta, koja prikazuje isparenja od zavarivanja sa mešavinom čestica, sa sferičnom ili fasetiranom morfologijom i često u lančanim strukturama (zaštitni gas: Ar–10 CO_2) [18]*

2. Experiment

2.1. GMAW/Manual welding, S235 J2G3/G3Si1

The goal of performed test was to find, how shielding gas influence to macroscopic view of the weld and additional work after welding. Welding parameters for samples are presented in Table 2.

Table 2. *Welding parameters for sample A and sample B*

Tabela 2. *Parametri zavarivanja za uzorak A i uzorak B*

	A	B
Base material	S235 J2G3, 8 mm thickness, plasma cutting edge, with oxide on surface	S235 J2G3, 8 mm thickness, plasma cutting edge, with oxide on surface
Welding parameters:	I= 225A, U=27V	I= 225A, U=27V
Welding consumables:	G3Si1, 1,2mm, cooper coated	G3Si1, 1,2mm, cooper coated
Shielding gas:	Ar+18 % CO_2, 12 l/min	multi-component mixture, 12 l/min
Welding machine:	Fronious TPS 400	Fronious TPS 400
Mode:	without pulse	without pulse
Welding position:	PA	PA

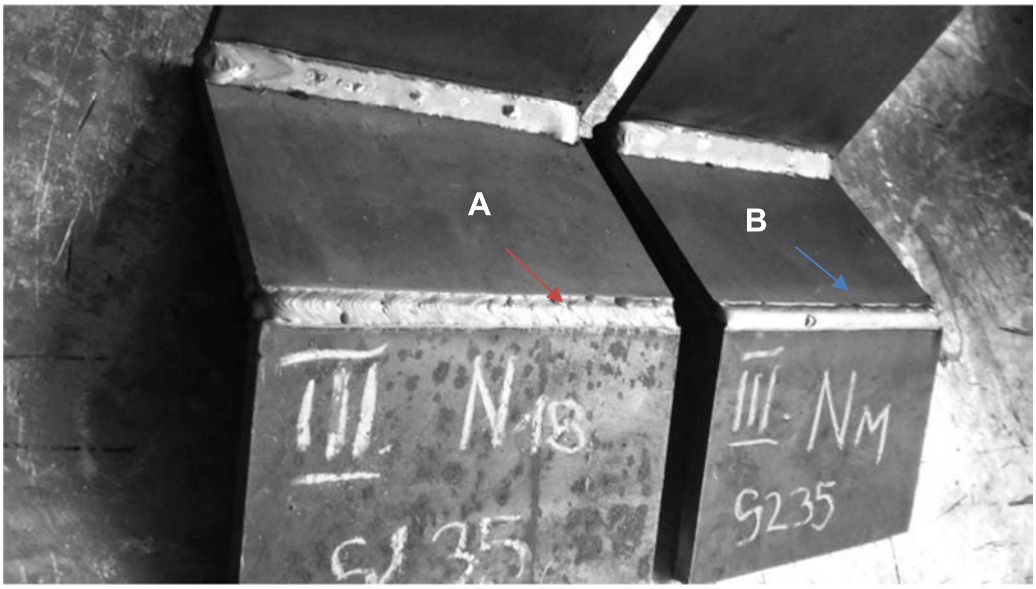


Figure 6. *Weld 1, shielded with Ar+18 % CO_2, weld 2 with multi-component mixture*

Slika 6. *Zavar 1, zaštićen sa Ar+18 % CO2, zavar 2 sa višekomponentnom mešavinom*

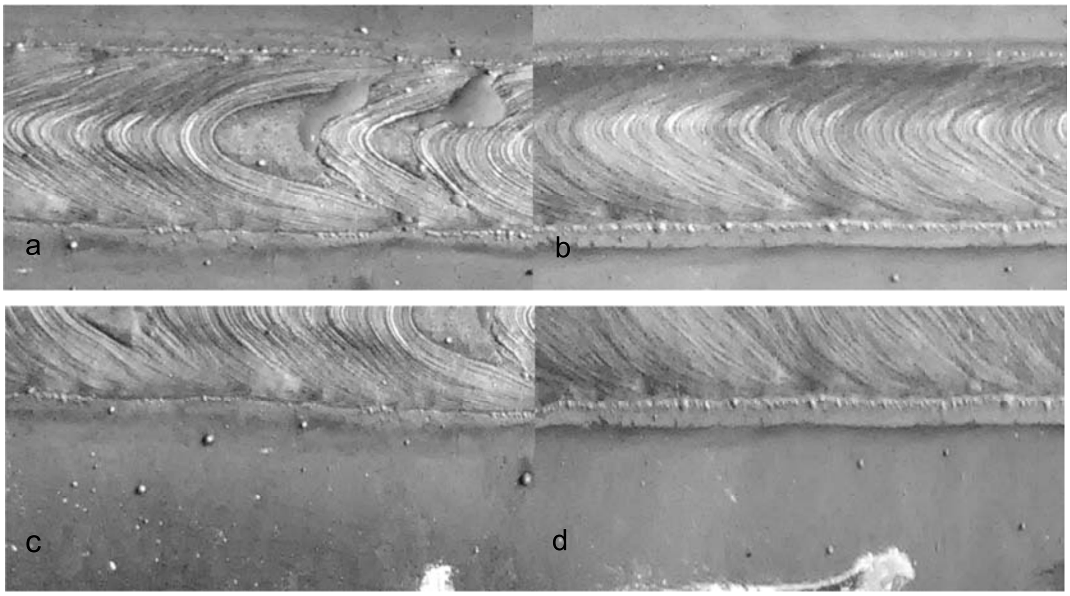


Figure 7. *Comparison of bead weld of both samples: a) bead weld A, b) bead weld B, c) edge of weld A, d) edge of weld B.*

Slika 7. *Poređenje šava oba uzorka: a) šav A, b) šav B, c) ivica šava A, d) ivica šava B.*

3. Results and discusion

Both samples were welded with same welding parameters, same welding consumable and same welding equipment. Same welder welded all welds. Welding speed was also observed.

3.1. Macroscopic view

3.1.1. Spatters

- On surface of base material near sample A, shielded with standard gas mixture Ar+18 % CO_2 we found more metal drops than on sample B, shielded with multi-component mixture.
- Diameter of drops on sample A was higher than on sample B. Most of them on sample A needed to be removed with grinding after welding. Drops on sample B were much smaller and can be removed without grinding.

3.1.2. Weld bead

Weld bea is smoother in sample B.

3.1.3. Slag on weld surface

Quantity of slag on surface is in connection with percentage of active gas in Ar. On sample A, more slag was observed than on sample B. Slag should to be removed before surface protection.

3.1.4. Welding speed

No difference in welding speed between both samples was observed.

4. Conclusion

To decrease total costs of arc welding process for industrial applications, especially for wide used GMAW welding, suppliers of shielding gases, welding consumables and welding equipment all the time present new solutions from their point of view. Shielding gases influence to weldability and welding speed. They influence on shape of weld bead, penetration depth , amount of slag on surface, quantity of spatters, size of individual spatter and consequently possibility, that spatter bond with basic material. In duplex, superduplex and steels with N, added nitrogen to shielding gas stabilize austenite microstructure. Some of gas mixtures for GMAW also increase welding speed and reduce total time of welding process. Speed can be increased for about 10 % in comparison to Ar+18 % CO_2. With multi-component mixtures is possible to reduce emission of fume gases, which is important for welder health. Multi-component mixtures are less universal than Ar+18 % CO_2, for their optimum use is important close cooperation with specialists from gas supplier company.

4. Zaključak

Da bi smanjili ukupne troškove procesa elektrolučnog zavarivanja za industrijsku primenu, posebno za široko rasprostranjeno MAG zavarivanje, dobavljači zaštitnih gasova, potrošnog materijala za zavarivanje i opreme za zavarivanje konstantno nude nova rešenja. Zaštitni gasovi utiču na zavarljivost i brzinu zavarivanja. Oni utiču na oblik šava, dubinu prodiranja, količinu troske na površini, količinu prskanja, veličinu pojedinačnih kapljica i posledično na mogućnost da se prskanje spoji sa osnovnim materijalom. U dupleksu, superdupleksu i čelicima sa azotom, dodatkom azota u zaštitni gas stabilizuje se mikrostruktura austenita. Neke od gasnih mešavina za MAG postupak, takođe povećavaju brzinu zavarivanja i smanjuju ukupno vreme procesa zavarivanja. Brzina se može povećati za oko 10 % u poređenju sa Ar+18 % CO2. Sa višekomponentnim mešavinama moguće je smanjiti emisiju dimnih gasova, što je važno za zdravlje zavarivača. Višekomponentne smeše su manje univerzalne od Ar+18 % CO2, a za njihovu optimalnu upotrebu važna je bliska saradnja sa stručnjacima kompanije za snabdevanje gasom.

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