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*Original Article*

# Use of Combined Gas Supply to Increase Thermal Efficiency of Plasma Processes

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***Abstract*** — *The results of comparative studies of heat transfer to the plasma torch elements and product simulator are presented in this article. The possibility of a significant increase in heat transfer to the product during plasma treatment with a plasma jet by changing the connection diagram of the plasma torch and using a combined supply of plasma and shielding gas is shown.*

**Keywords —** *Heat transfer, Plasma arc, Plasma treatment, Plasma torch.*

## I. INTRODUCTION

Controlling heat transfer in the product makes it possible to increase the productivity and quality of plasma processing of metals [1]-[3].

An increase in the heating capacity of the compressed arc due to an increase in the current leads to an increase in heat input into the plasma torch elements that, in its turn, adversely affects the service life of the plasma torch and trouble-free operation in general [4]. In addition, there is a connection between the value of the welding current and geometric parameters of the plasma torch - the diameter and height of the plasma-forming nozzle channel in particular [5]. For each specific geometric parameter, there is a critical current value, and it's exceeding leads to emergency mode [6].

Specific heat content (enthalpy), i.e. the amount of heat contained in a unit of volume or mass of the arc is an important parameter of a compressed arc (Fig. 1). The use of high-enthalpy molecular plasma-forming gases is energetically more profitable since they have the same thermal efficiency as monatomic gases at lower temperatures [7]. At the same time, heat loss due to radiation into the walls of the plasma torch and the environment is reduced. The influence of the plasma-forming gas on plasma arc thermal characteristics has been studied in sufficient detail in previous years [8].

Shielding gases have a great influence on the quality of the welded joint [9]. To ensure quality, it is necessary to use a shielding gas suitable for the material to be processed [10], [11]. In this case, their physical properties such as ionization and dissociation energy, thermal conductivity, atomic mass, and chemical reactivity have critical importance. Inert and active gases, as well as their mixtures, are used as shielding gases [12]-[13].

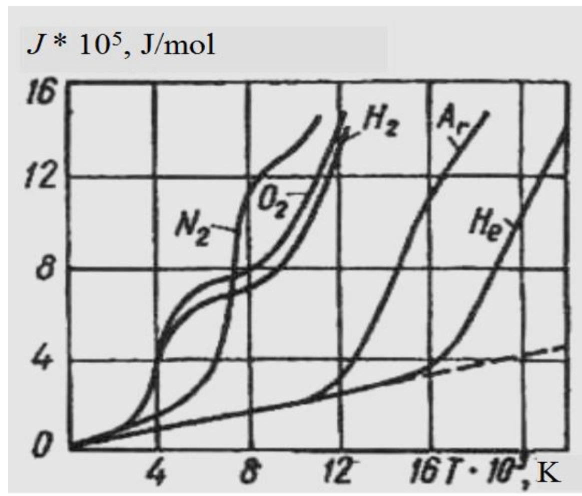


**Fig. 1 Plasma enthalpy about temperature**

Inert gases protect the arc and the welded metal without metallurgical influence. Argon, due to its high atomic mass, provides effective protection of the treatment area. It occurs as a result of achieving the large kinetic energy of the plasma jet. Low ionization potential provides high voltage and high-frequency discharge. However, argon has low thermal conductivity and low heat capacity. During welding copper, it is advisable to use nitrogen, because nitrogen is inert concerning copper. In terms of properties (thermal conductivity, enthalpy, and atomic mass), nitrogen can be placed between argon and hydrogen. Active shielding gases, such as carbon dioxide ($CO_2$), are mainly used for welding structural steels because the gas enters into chemical interaction with the welded metal and dissolves in it. Gas mixtures have, in some cases, better technological properties than individual gases. For example, a mixture of argon with carbon dioxide allows alloyed steels to be welded without burning out the alloying components while reducing spatter and increasing penetration depth.

**Table 1. Process parameters**

| I, A | dnozzle, mm | Q plasma., l/min | Qshield. , l/min | The polarity of the current |
|---|---|---|---|---|
| 50-250 | 4 | 3.0 | 1.7/5.5/7 | direct/reverse |

## II. METHODS

The purpose of this work was to study the effect of different shielding gases on the energy parameters of the plasma arc. The studies were carried out in the following order: the heat input into the plasma torch and the product was measured depending on the arc current magnitude and the type and consumption of the shielding gas when operating on a current of direct and reverse polarity. The study of heat input into the plasma torch and the product were carried out by the calorimetry method. Cooling of the plasma torch and the product was implemented using running water. An ESAB LHF-400 power source was used to power the compressed arc with a welding current. Argon (Ar), nitrogen ($N_2$), and carbon dioxide ($CO_2$) were chosen as shielding gases. The studies were performed with the following model parameters (Table 1).

The arc voltage varies depending on the shielding gas used as shown in Table 2.

**Table 2. Arc voltage changed**

| I, A | $U_{EI}$, V | | | | | |
|---|---|---|---|---|---|---|
| | Direct polarity | | | Reverse polarity | | |
| | Ar | $N_2$ | $CO_2$ | Ar | $N_2$ | $CO_2$ |
| 50 | - | - | 21.6 | 35 | 31.7 | 32.9 |
| 100 | 18 | 26.2 | 23 | 36.3 | 34.3 | 36.4 |
| 150 | 19.5 | 28 | 24.2 | 39.2 | 35.3 | 39.1 |
| 180 | 22.5 | 29.5 | 26.3 | - | 39.7 | 39.9 |

## III. RESULTS

When operating in argon at reverse polarity current, the arc voltage increases by about 2 times as compared to operating at direct polarity, and the electric power of the arc also increases accordingly (Table 2).

The measurement results are summarized in graphs of the dependence of heat input into the product on the current.

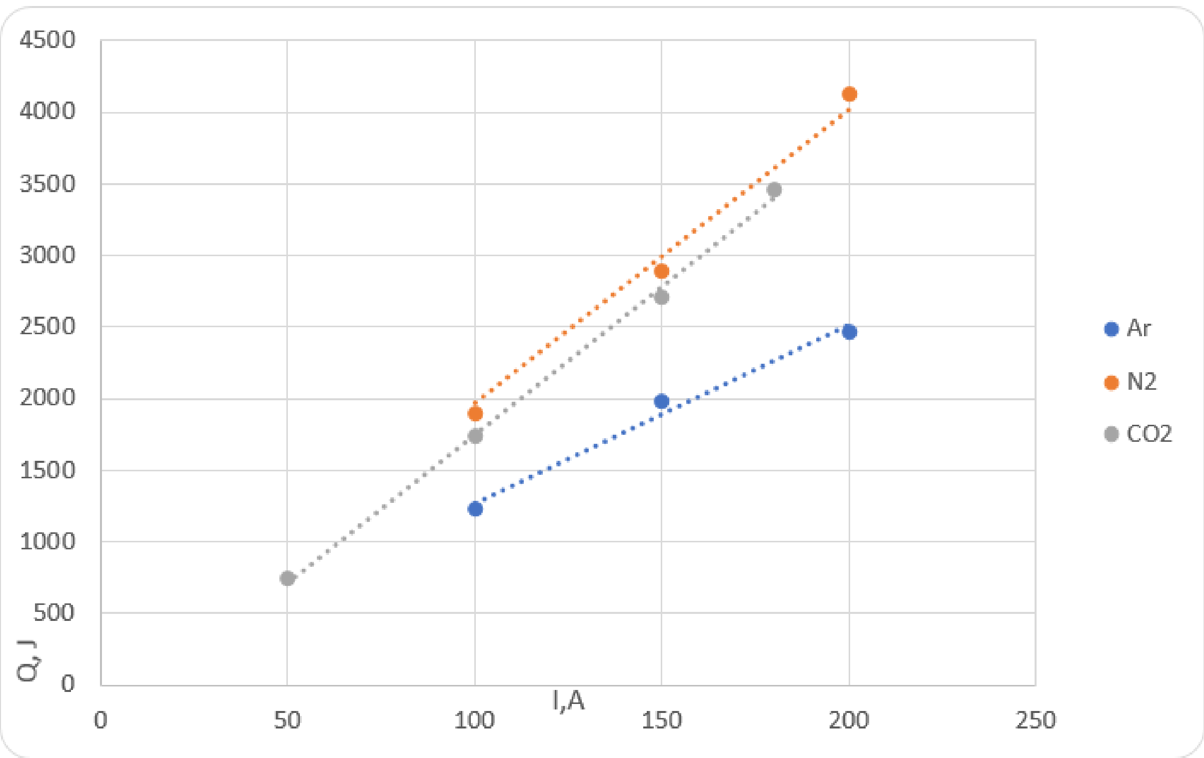


**Fig. 2 Dependence of heat input into the product on the current when operating on direct polarity**

When operating at direct polarity current, the greatest heat input into the workpiece, other conditions being equal, is achieved when nitrogen is used as a shielding gas. In the area of the high current, the heat input into the product is more than doubled in comparison with argon (Fig. 2).

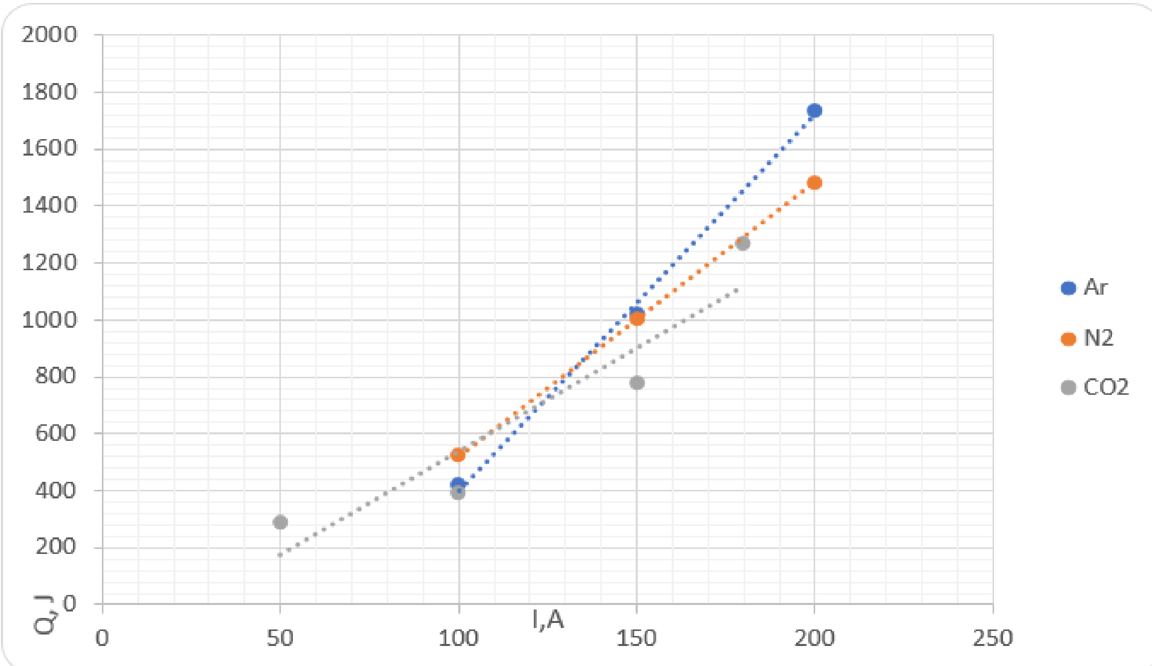


**Fig. 3 Dependence of heat input into the plasma torch on the current when operating on direct polarity**

When using carbon dioxide, the plasma torch carries the least heat load, but the heat input into the product also decreases (Fig. 3).

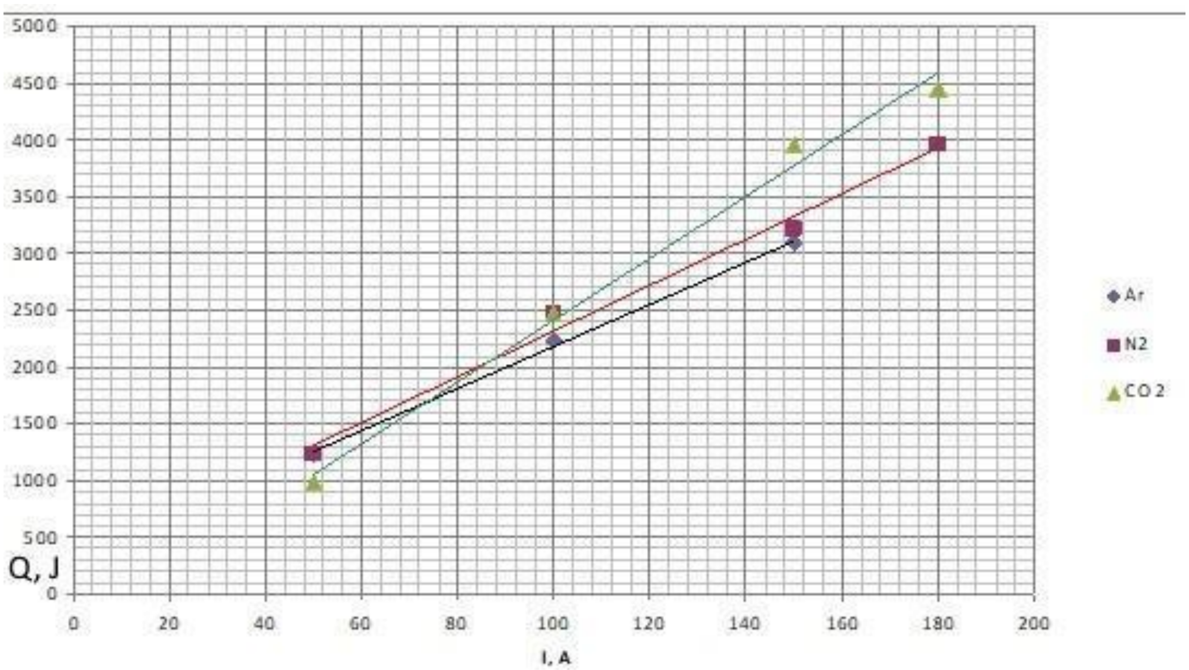


**Fig. 4 Dependence of heat input into the product on the current when operating on reverse polarity**

The use of nitrogen and carbon dioxide makes it possible to increase the heat input into the product in high currents area by about 1.7 times in comparison with argon (Fig. 4).

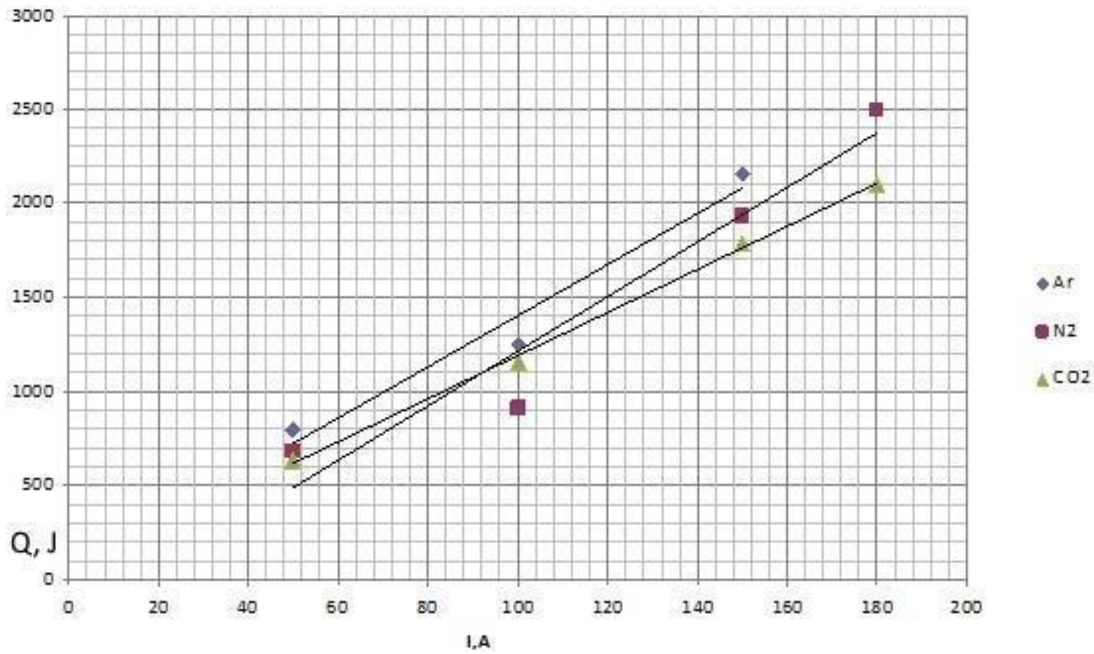


**Fig. 5 Dependence of heat input into the plasma torch on the current when operating on reverse polarity**

When the plasma torch operates at a current of reverse polarity in low currents area, when all types of shielding gases are used, the plasma torch carries a similar thermal load. However, in high currents area, when carbon dioxide is used, a decrease in heat input to the plasma torch by about 1.5 times is observed (Fig. 5).

## VI. CONCLUSION

- It was found that when operating at reverse polarity current, all other conditions being equal, the heat input into the product increases by about 1.3 - 1.5 times, however, an increase in thermal load on the plasma torch reduces the efficiency of the process.
- With the same arc current, the highest arc voltage is achieved when using nitrogen as a shielding gas, this affects the electric power of the arc, and therefore the thermal power. The lowest voltage is achieved when argon is used as shielding gas.
- When using high-enthalpy gases - nitrogen and carbon dioxide, the heat input into the plasma torch is reduced by 1.2-1.5 times.
- The use of a combined supply of shielding and plasma-forming gas, with constant energy consumption, makes it possible to increase the thermal efficiency of the process, however, the technological features of plasma treatment of certain groups of materials, in particular aluminum and titanium alloys, should be considered. When processing such materials, one hundred percent shielding gas is required and therefore using of an inert gas (argon). During operation at reverse polarity, nitrogen and carbon dioxide, unlike argon, do not provide the proper effect of cathodic cleaning of the processed surface.

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