



# COBALT-BASED ALLOYS FOR SURFACING

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Many modern steel structures are characterized by high mechanical properties of joints, as well as good corrosion resistance of the applied materials. Coating of base materials with selected mechanical properties using surfacing by flux-cored wire based on cobalt is a reliable way to obtain the desired combination of properties, such as corrosion and wear resistance. The advantages of flux-cored wires by providing a diverse chemical composition of the deposited metal, reliability and high efficiency are proved in many industrial applications. This article describes examples of using Co-based flux-cored wires in two different welding processes (surfacing using TIG and MIG method). Different slag systems of wires and their properties are presented. Moreover a comparison with other arc surfacing processes is made. On the specific examples the diversity of applications of flux-cored wire based on cobalt is shown. The influence of different parameters on surfacing process is discussed. 11 Ref., 4 Tables, 10 Figures.

**Keywords:** arc surfacing, metal flux-cored wire, cobalt base, production, alloying, standardization, properties, application

**Production of Co-based flux-cored wires for surfacing.** Flux-cored wires based on cobalt for surfacing are rolled. So far only the flux-cored wires with overlapping strip are known (Figure 1).

Production of cobalt flux-cored wires of seamless type is not possible so far due to a lower degree of filling. The flux-cored wires based on cobalt are metal powdered ones (M-type). Unlike medium- and highly-alloyed flux-cored wires for surfacing of corrosion- and wear-resistant layers, which mainly consist of non-alloyed strip and highly-alloyed filling, the high-quality alloyed flux-cored wires based on cobalt are composed of pure cobalt and filler containing alloying elements, deoxidizers, elements for stabilization of arc and slag-forming ones.

To achieve the accurate roundness of wire before its winding on the coil in manufacture after rolling stages the drawing is applied using accurate diamond dies. The principle of wire manufacture is shown in Figure 2.

The metal flux-cored wires provide a very fine-drop metal transfer in surfacing and are characterized by absence of slag on the surface. The particles of manganese and silicate oxides located on the surface of the weld are easily removed. Except of high deposition rate using wires of M-type a significant penetration of base metal is achieved. These flux-cored wires can be used in all spatial positions. The use of pulsed technique is preferable. In general, the wires of M-type are surfaced in shielding gases according to the stand-

ard DIN EN ISO 14175. Here, gases of the class 11 or M1x are applied. Cobalt flux-cored wires are also applied as a filler material in surfacing using non-consumable tungsten electrode (TIG method). In this case the wire feed can be realized in cold or preheated conditions. Moreover, flux-cored wires based on cobalt can be surfaced without shielding gas. In this case, the flux-cored wires belong to the type *U*. They are used for single and multipass surfacing in flat position. Filling of such wires consists of alloying elements, stabilizers of arc and also gas-forming elements, as well as slag-forming addition is possible.

**Alloying groups.** In Table 1 the conventional welding processes used for corrosion-resistant surfacing by cobalt flux-cored wires, types of protection and positions of surfacing are shown.

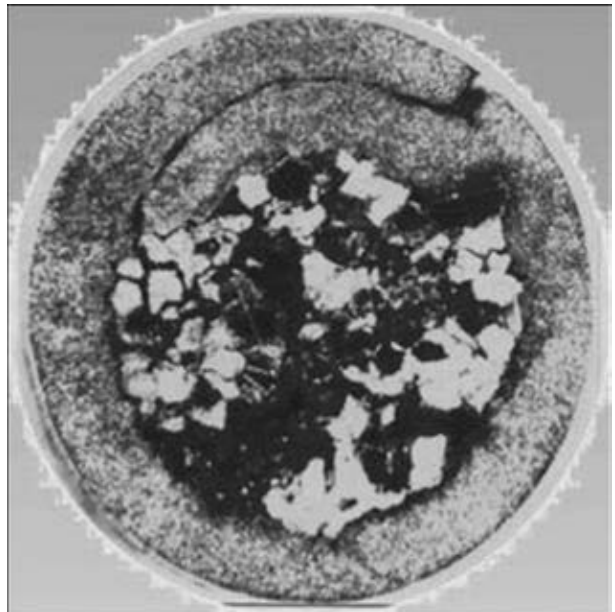


Figure 1. Rolled flux-cored wire with strip overlapping

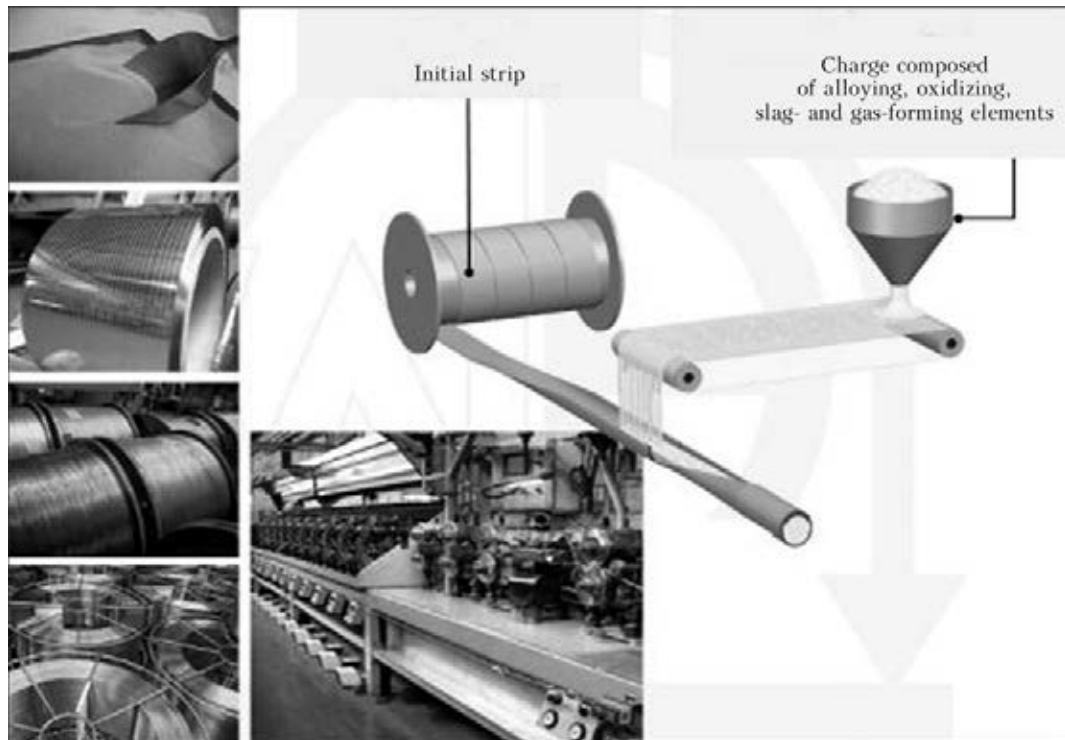


Figure 2. Production of Co-based flux-cored wires

**Standard alloys.** Table 2 the typical alloys are illustrated with hardness values of weld metal at the room temperature and up to 800° C. Further the main fields of their application are shown. Today alloys 21 and 6 are among those, which are going to find the widest application in industry, in particular for surfacing of valve seats and sealing surfaces in oil or gas industry. These alloys possess an optimum combination of resistance to abrasion, corrosion and impact effects, at that, deposits have no cracks at strictly controlled surfacing parameters.

**State-of-the-art of standardization.** The international standardization (EN and ISO standards) as well as national regulations allows clas-

sifying filler materials for surfacing. However, over flux-cored wires there is a special situation. Not for each alloying system the standard is available. Table 3 provides overview of state-of-the-art of classification standards for arc surfacing.

**Properties of surfacing coatings.** Cobalt flux-cored wires are classified in the frames of materials for surfacing according to EN 14700 and in ASME II C SFA 5.21 even the standard materials for surfacing based on cobalt can be found.

**Influence of technological parameters.** Arc surfacing using flux-cored wire usually has a higher efficiency (up to 10 kg/h or 0.4 m<sup>2</sup>/h) as compared to solid wire electrodes, but has no their disadvantages in surfacing.

The penetration profile is similar to the profile in arc surfacing using electrodes. However the penetration depth can be reduced. In surfacing using cobalt flux-cored wires it is possible to control the penetration and thereby the iron content in the deposited layer (Figures 3 and 4).

It requires optimization of process parameters for surfacing using cobalt flux-cored wires.

The influence of technological parameters in arc surfacing using flux-cored wire can be described as follows:

- *welding current*: width and bead reinforcement as well as penetration are increased with increase in current strength;
- *rate of surfacing*: width and bead reinforcement are decreased with increase in welding

Table 1. Alloying groups

Alloying group	Cobalt base	
	STELLOY	
WA Cored Wires TM	G	O
Welding process acc. to N ISO 4063	139	114
Welding process acc. to AWS	FCAW-G	FCAW
	FCAW-P	–
AWS classification: Filler type	ERCCoxxx Metal powder	ERCCoxxx Self-shielding
	M	U
Welding position	PA	PA
Shielding gas acc. to ISO 14175	I1, M1x	–

**Table 2.** Typical standard alloys

Type	1	6BC	6	6HC	12	21	25
	Wire diameter, mm						
Stelloy-G MIG	1.2, 1.6, 2.4	1.2, 1.6, 2.4	1.2, 1.6, 2.4	1.2, 1.6, 2.4	1.2, 1.6, 2.4	1.2, 1.6, 2.4	1.2, 1.6
Stelloy arc welding electrodes	2.5–5.0	N/A	2.5–5.0	N/A	2.5–5.0	2.5–4.0	2.5–4.0
Stelloy TIG wire	N/A	1.2–1.6	1.2–1.6	1.2–1.6	N/A	1.2–1.6	N/A
EN 14700	TCo3	TCo2	TCo2	TCo2	TCo2	TCo1	TZCo1
Typical chemical composition of weld metal, wt.%	C 2.3 Cr 29 W 12 Mn 1.0 Si 1.0 Fe 4.0 Co – base	C 0.9 Cr 28.5 W 4.5 Mn 1.0 Si 1.0 Fe 4.0 Co – base	C 1.05 Cr 28.5 W 4.5 Mn 1.0 Si 1.0 Fe 4.0 Co – base	C 1.2 Cr 28.5 W 4.5 Mn 1.0 Si 1.0 Fe 4.0 Co – base	C 1.5 Cr 30 W 7.5 Mn 1.0 Si 1.0 Fe 4.0 Co – base	C 0.25 Cr 28 Mo 5.5 Mn 1.0 Ni 3.0 Si 1.0 Co – base	C 0.15 Cr 20 W 14 Mn 1.5 Ni 9.5 Si 1.0 Fe 4.0 Co – base
Hardness <i>HRC</i> of weld metal at 20 °C	53	38	Work hardens 42	44	45	Work hardens 33	21
Hardness <i>HB</i> at 200 °C	495–560	350–380	380–415	410–430	415–455	300–340	210–260
400 °C	465		370		410	280	180
600 °C	420		320		370	255	145
800 °C	370		255		315	235	130
	330		240		275	220	120
Resistance to cracking	*	****	***	**	**	****	****
Impact toughness	*	***	***	**	**	****	****
Metal-to-metal wear	***	***	***	***	***	****	****
Corrosion	****	****	****	****	****	****	****
Wear in the cold state	****	**	***	***	****	**	**
Wear in the hot state	****	**	***	***	****	**	***
Machining of the material	****	**	**	**	**	****	****

speed, penetration depth and degree of mixing with base metal are increased with increase in welding speed;

- *arc length*: penetration depth and degree of mixing with base metal are decreased with increase in length of the arc;

- *torch position*: with inclination of torch forward the penetration depth, degree of mixing with base metal and bead reinforcement are increased; with increasing the inclination angle of torch this effect is intensified, and width of the weld is reduced;

- *preheating*: penetration depth, degree of mixing with base metal and weld width are increased with increase in preheating temperature, and bead reinforcement is reduced;

- *shielding gas*: the higher is content of CO<sub>2</sub> in shielding gas, the greater is penetration depth and degree of mixing with base metal. The degree of mixing is increased by applying gases (without helium) in the following order: I1 < M13 < M12 < M20 < M21 < CO<sub>2</sub>.

**Comparison of gas arc surfacing using cobalt flux-cored wire with other processes of surfac-**

**Table 3.** Classification of standards for flux-cored wires

Standard	Material						
	Low carbon and low alloyed steels	High strength steels	Heat-resistant steels	Stainless and heat-resistant steels	Nickel alloy	Cast iron	Hard alloys
DIN	8559	–	–	–	–	8573	8555
EN	758	12535	12071	12073	–	1071	14700*
ISO	17632*	18276*	17634*	17633*	12153	1071*	–

\* Acting state standards.

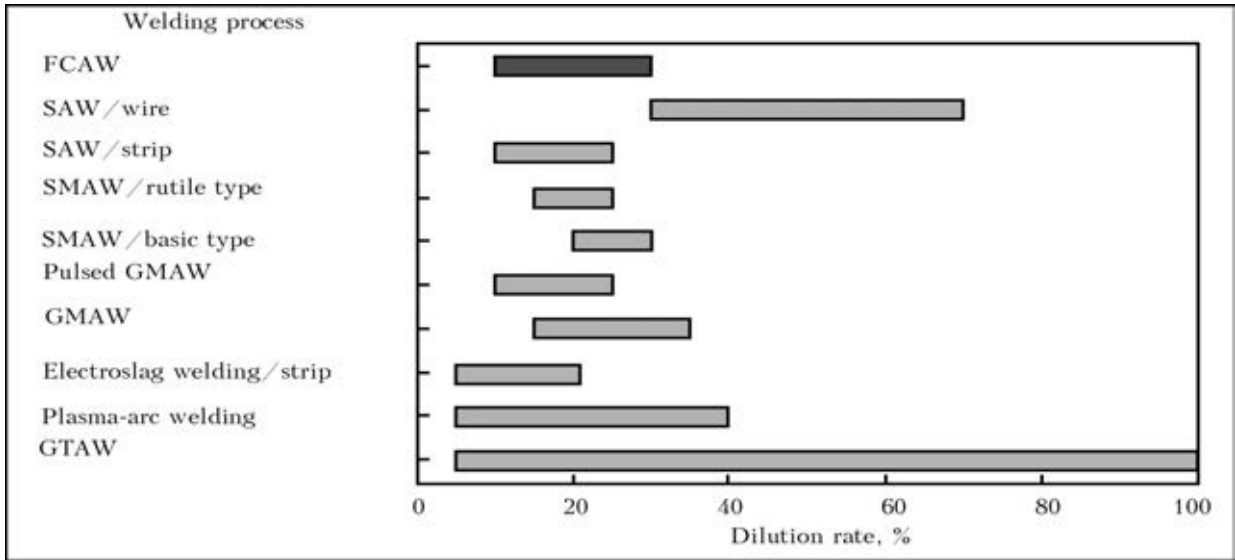


Figure 3. Penetration depth depending on method of surfacing

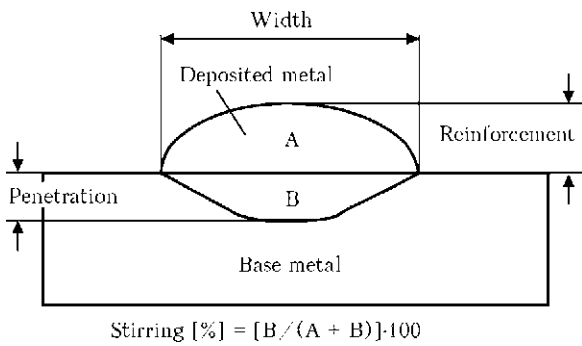


Figure 4. Determination of penetration coefficient

ing. The arc surfacing using flux-cored wire has several advantages as compared to other processes of arc surfacing. They include low heat input; low deformation; poor mixing with base metal; possibility of single-layer surfacing; presence of great diversity of possible chemical compositions of deposited metal; possibility of surfacing in different spatial positions; low volume of further treatment.

Table 4 reflects the important distinctive criteria for different methods of surfacing. High purity of deposited metal using flux-cored wire based on cobalt is shown in Figure 5. This imaging shows the corresponding microstructure.

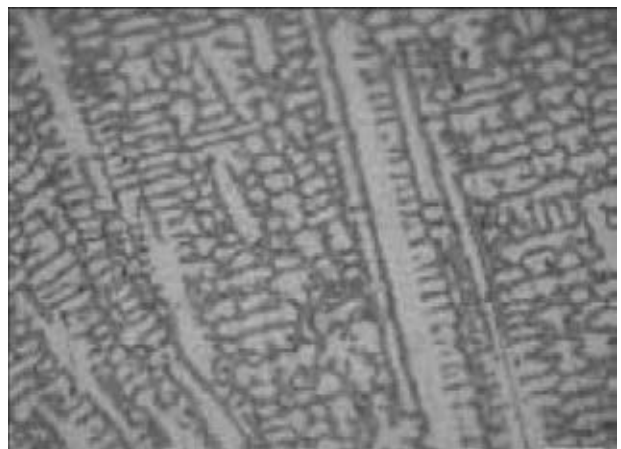


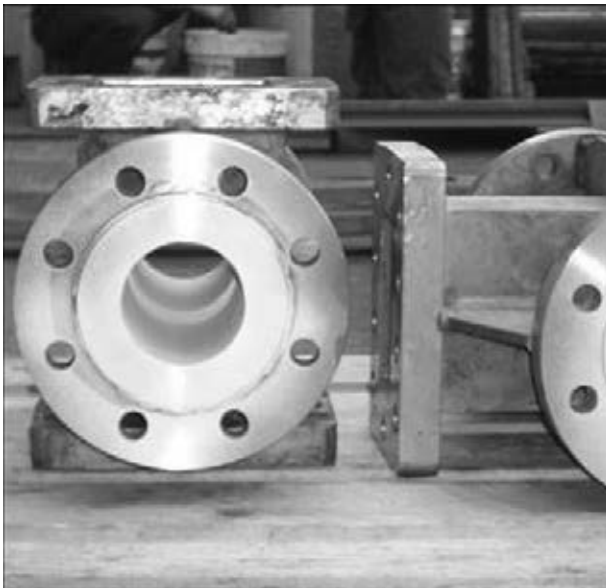
Figure 5. Microstructure of metal deposited using wire Stelloy 1-G

Here it is noteworthy that dendritic structure is characterized by a very high purity.

**Examples of application.** The following examples demonstrate the variety of flux-cored wires based on cobalt. The alloys based on cobalt are used at high temperatures, where there is a high wear and corrosion resistance, for example, for high pressure sealing surfaces, screw conveyors of extruders in production of plastics, moulds in ceramic industry, tools in forge industry, hot

Table 4. Comparison of different surfacing methods

Process	Automation	Efficiency of melting, kg/h	Investments	Welding positions	Advantages	Restrictions
GTAW/hot wire	+	1-2	High	All	High quality	Sizes/expenses
GTAW/FCW	+	3-5	Medium	All	Same	Efficiency
GTAW/solid wire	+	1-2	Same	1G/3G (PA, PG)	Cost	Quality
SMAW	-	0.5-2	Low	All	Flexibility	Possibility of automation
ESW	+	Up to 25	High	1G (PA)	Price/kg of deposited metal	Sizes

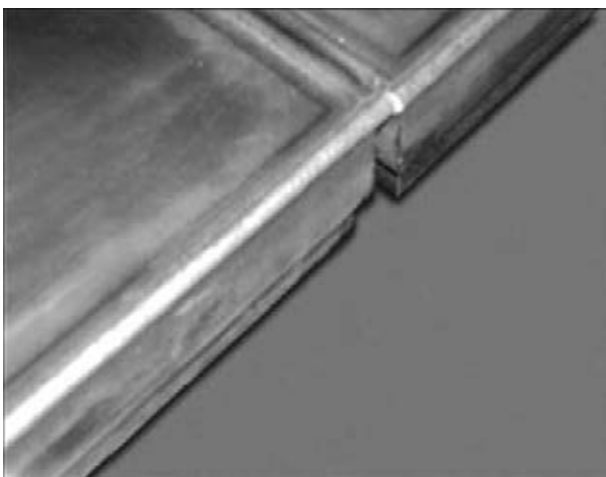


**Figure 6.** One-layer Hastelloy 6 coating produced using TIG method

shears or valves. For various alloys the corresponding flux-cored wires can be manufactured. They can be deposited using arc surfacing with or without using the pulsed technique. It is preferable to use pure argon as a shielding gas. In TIG surfacing as a shielding gas argon or mixture Ar + He can be used.

Figure 6 shows TIG surfacing with Hastelloy 6 on valve seat. For a buffer layer in this case steel of 309L type can be used. Figure 7 shows MIG surfacing with Hastelloy G-6 for ceramic mould. Figure 8 shows single-layer arc surfacing using cobalt flux-cored wire of type Stelloy 21-G on the motor valve surface.

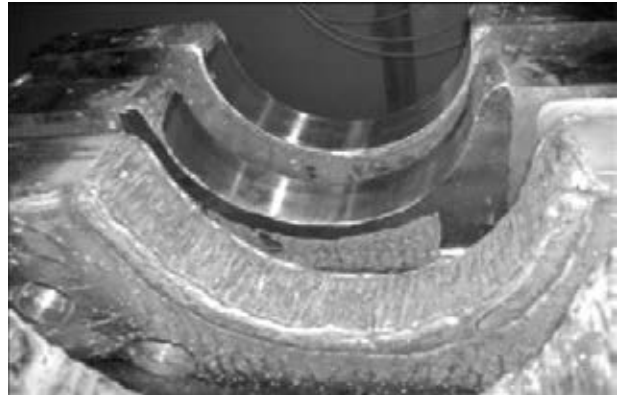
Another example of application of high-cobalt alloys can be brought from the steel industry. Hot knives cut steel rods and slabs at the temperature of 800 °C. Due to a long contact with hot material the knives are exposed to thermal fatigue and it is necessary to protect them. Fi-



**Figure 7.** Surfacing of edges with alloy Hastelloy G-6



**Figure 8.** Surfacing of valve with alloy Stelloy 21-G



**Figure 9.** Multilayer surfacing of knife blade for hot cutting

gure 9 shows a typical multi-layered surfacing on hot cutting knife. After surfacing the heat treatment and subsequent machining are carried out.

**Thermal conditions in surfacing using cobalt flux-cored wires.** In most cases, the main criterion for producing high quality coating of Co-based alloy is producing of deposits without cracks and with high hardness. The hardness of pure metal is in the range *HRC* 21–53 for standard alloys (see Table 2). At such a high hardness it is necessary to provide special measures to control heat input. First of all, the temperature of preliminary and interlayer heating must be strictly controlled and constantly maintained. The preheating depends on the type of base material, number of layers, thickness of walls.

As a rule, cobalt flux-cored wires of type 6 are deposited with preheating of not less than



**Figure 10.** Macrosection of Hastelloy 6-G deposit with steel 309L buffer layer



200 °C in single-layer surfacing. Preheating can be increased to 400 °C in some cases.

The cooling rate of cobalt deposits is also an important criterion. In many cases martensite transformation in base metal steel leads to local stresses, which can overload the brittle deposited metal and result in cracking.

**Buffer layers.** The use of buffer layers allows decreasing the temperature of preheating for the coatings sensitive to cracking. As a rule, the steels based on iron, such as 309L or nickel alloys like Inconel 625, can be used for this purpose. Figure 10 shows macrosection of the cobalt-based alloy deposit with buffer layer of steel 309L produced using cobalt flux-cored wire Hastelloy 6-G.

The method of application of buffer layers affects hardness of deposited layer, therefore the control of technology is required. The selection of alloy for buffer layer depends also on need in the subsequent heat treatment.

**Trends for the future.** Nowadays the majority of cobalt flux-cored wires are surfaced using arc method with consumable electrode. Another method of surfacing is using the automated TIG process. Striving for higher quality and efficiency of TIG surfacing resulted in using the technology with hot wire. For this purpose the compositions of charges of flux-cored wires are optimized only for TIG process. For standard alloys, such as alloys 6 and 21, the cobalt flux-cored wires for TIG welding of 1.2 mm diameter already exist.

### Conclusion

Today cobalt flux-cored wires have many possibilities of application in the field of surfacing of corrosion- and wear-resistant layers. High qual-

ity types of deposited metal, high efficiency, economy of expenses, flexibility of compositions of alloys and excellent welding characteristics are the main arguments for their application.

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Received 12.05.2014