Verification of additional welding materials material features – during welding steel structures

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Welding materials - Quality requirements for the production of welding materials and related processes

Abstrakt:

Článek je zaměřený na požadavky jakosti pro výrobu přídavných materiálu. Vychází z výrobkové normy EN 13479 a poukazuje na proces spojení s výrobou vzorku, jejich úpravou před zkoušením dle normy a následné zkoušení dle daných norem. Závěrem článku jsou prezentovány výsledky a vyhodnocení daného přídavného materiálu.

Abstract:

The article focuses on quality requirements for the production of additional materials. It is based on product standard EN 13479 and indicates the process of connection with the production of the sample, its modification before testing according to the standard and then testing according to the given standards. The end of the article presents the results and evaluation of the additional material.

INTRODUCTION

Welding is process which serves to create permanent rigid joint of two or more parts. Generally welding is about creating such thermo - dynamical conditions, during which it is possible to form inter-atomic bindings. These rigid joints have similar composition as the base material. They result from action of temperature, or pressure and also with possible use of additional material.

Welding with the use of heat, known as fusion welding. During fusion welding comes to joint by local positioning of the base material welding edges, without use of press or impacts. Usually this happens with the use of additional materials of the same or similar chemical composition. Verifying of additional material features is most convenient to do straight in production, where WPQR approval test serves for such purposes.

Selection of additional materials for welding steel structures (MIG/MAG – 135)

Selection of additional materials for welding of the group of materials 1.1 and 2.1 is governed by the principle of resemblance with welding material, considering its chemical composition and mechanical features. According to the standard EN 1993-1-8 should be the specified yield point tensile stress, maximum elongation and notch toughness of additional material the same, or better than features of the base material. Generally it is safe to use welding electrodes which have required features better than steel of the used strength category. The kind of additional material must be in accordance with the method of welding.

While selecting additional material it is also necessary to realize one more important fact and that is that the value of yield point and tensile strength of the all - weld metal are very close. This small difference doesn´t have to correspond to mechanical features of the base material. ***During selection of additional material with the same specific yield point as the base material, the value of the tensile strength of the weld metal is usually considerably lower than the value of tensile strength of the base material. This fact leads to discrepancy during qualifying tests or, and this case is worse, it leads to failure in service itself.***

Note: In the example the base material *S355J2+N is used, that means the minimal specified yield point is 355 MPa. If we want the additional material to have the same or higher strength than the base material, we have to select rank up to G 42 (according to EN ISO 14341), that means welding wire with the minimal yield point 420 MPa.*

In Tab.1 in example used additional materials base features are presented.

Tab. 1 Features of the used additional materials

Welding wire	**Use**	**Mechanical features of the weld metal**	**Chemical composition of the welding wire**
		Values declared by producer [weight %]	
KOWAX Speed Road G3Si1 Ø1.0 Classification according to EN ISO 14341-A: G 42 4 M21 3Si1	Coppered wire suitable for welding of structure steel in shielding gas CO_2 or in shielding gas mixture.	$R_{eL/Rp}$ = 441 MPa (for M21) R_e = 486 MPa (for C) R_m = 538 MPa (for M21) R_m = 570 MPa (for C) A = 35 % (for M21) A = 29 % (for C) KV = 75 J / T = -40 °C (for M21) KV = 71 J / T = -30 °C (for C)	C = 0.08 Ni = 0.014 Si = 0.89 Cr = 0.013 Mn = 1.45 M = 0.014 P = 0.019 V = 0.02 S = 0.013 Cu = 0.002 Al = 0.01 Ti+Zr = 0.13

Note: *EN ISO 14341-A (Wire electrode and weld metal for arc welding by consumable electrode in shielding gas unalloyed and fine-grained steel) Identification will be: EN ISO 14341-A G 42 4 C1/M1 3Si1 where:*

EN ISO 14341-A *- number of the international standard, where classification A is based on scale of yield point and minimal impact test* ***KV = 47 J*** *with the given test temperature of all - weld metal (preferentially used system in our common practice). Tab.1*

G - symbol for identification of weld metal for arc welding with electrode in protective atmosphere,

42 -identification for physical property of weld metal ***ReL min. / Rp0,2 $_{min}$. = 420 [MPa], Rm =*** *500 up to 640* ***[MPa], Amin = 20 [%]***

4 - symbol for identification of impact test of weld metal. Temperature for minimal impact test ***47 J = -40 [^{o}C]***

C1/M1 - symbol for identification of shielding gas according to EN ISO 14175 in protection gas CO_2 or in shielding gas mixture.

3Si1 - symbol for identification of chemical composition of the wire in ***maximal content of elements indicated in weight percentage, for***

C = 0.06-0.14, Si =0.5-0.8, Mn=0.9-1.3, P=0.025, S=0.025, Ni=0.15, Mo=0.15, Al=0.02, Ti+Zr=0.15, Cr=0.15, Cu=0.35

Verification of the values from attest with the use of own tests. The technique was selected according to international standard EN 13479 for weld materials (general production standard). Totally 6 samples were produced, version BW (butt weld joint). Examined additional material on which were the mechanical tests executed is KOWAX Speed Road G3Si1 1.0. Classification G3Si1 according to EN ISO 14341- A. Diameter 1.0.

RESULTS OF WELD METAL TESTING

Three samples of weld metal were used for the tensile test. Testing machine EU 40, number 990.56/6 was used for this test. Range 0-400 kN. Ambient temperature 21°C. Accredited test number of the test record 3-1/2016.

Sample identification	D_0	S_0	L_0	L_U	d_U	S_U	$R_{p0,2}$	F_m	R_m	A	Z	u_{RM}
	[mm]	[mm^2]	[mm]	[mm]	[mm]	[mm^2]	[MPa]	[kN]	[MPa]	[%]	[%]	[MPa]
1	10.03	79.01	50	63.3	5.41	22.99	**482**	45.0	**569**	27	71	1
2	9.99	78.38	50	65.2	5.38	22.73	**440**	42.0	**536**	30	71	1
3	10.03	79.01	50	64.3	5.78	26.24	**467**	44.3	**560**	29	67	1

Tab.2 results of observed values of the tensile test

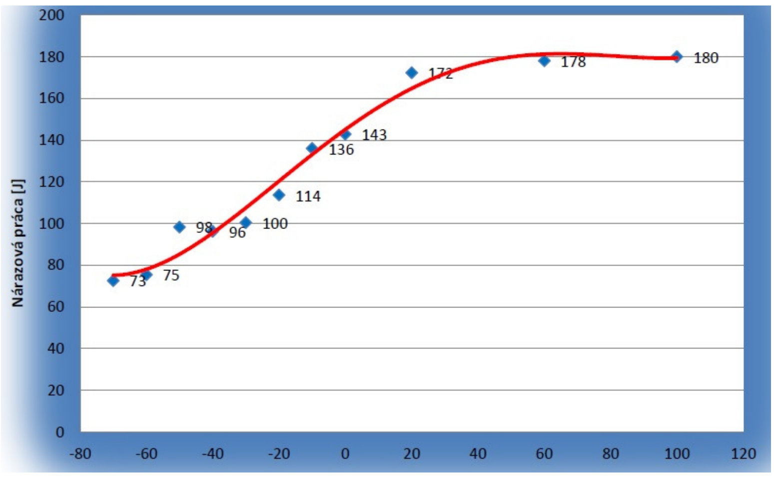
***Legend:** d – sample diameter , S – area of cross-section, Rp0.2 = tension on arranged yield point, Fm – strength on tensile strength point, Rm – tension on tensile strength, URm – uncertainty of measurement, Lo – original length of testing bar, Lu – length of the testing bar at the end of the testing, A – tensibility, Z – contraction.*

Test of the weld metal notch toughness was realized according to methodical instructions of the testing organization in conformity with standard EN ISO 148-1 (10 x 10 x V2) and EN ISO 9016. Pendulum testing impact machine with the range 300 J number 423/79 was used. Maximal energy of the pendulum testing impact machine is 300 J. Number of samples 55. Temperature limit from -70 °C to 100 °C. Accredited test number of the test record 3-/2016. There is graphical behaviour of dependence of absorbed energy on temperature change shown in picture no. 1.

Sample identification	a_0	b_0	h	S_0	KV_{-2}	KCV_{-2}	u_{KCV-2}	T
	[mm]	[mm]	[mm]	[cm^2]	[J]	[J/cm^2]	[J/cm^2]	[°C]
1	10.18	10.19	8.12	0.83	**119.0**	144	2	-40.9
2	10.19	10.18	8.18	0.83	**71.0**	85	2	-39.8
3	10.17	10.18	8.14	0.83	**109.0**	132	2	-39.1
4	10.17	10.19	8.10	0.83	**102.0**	124	2	-41.0
5	10.17	10.16	8.12	0.82	**80.0**	97	2	-40.2

Tab.3 measured values KCV in temperature – 40 °C

***Legend:** a0, b0 – cross-section size, h – length of testing bar in the place of notch, So – area of cross-section in the place of notch, KV-2 – impact test, KCV-2 – notch toughness, uKCV-2 – combined standard uncertainty*

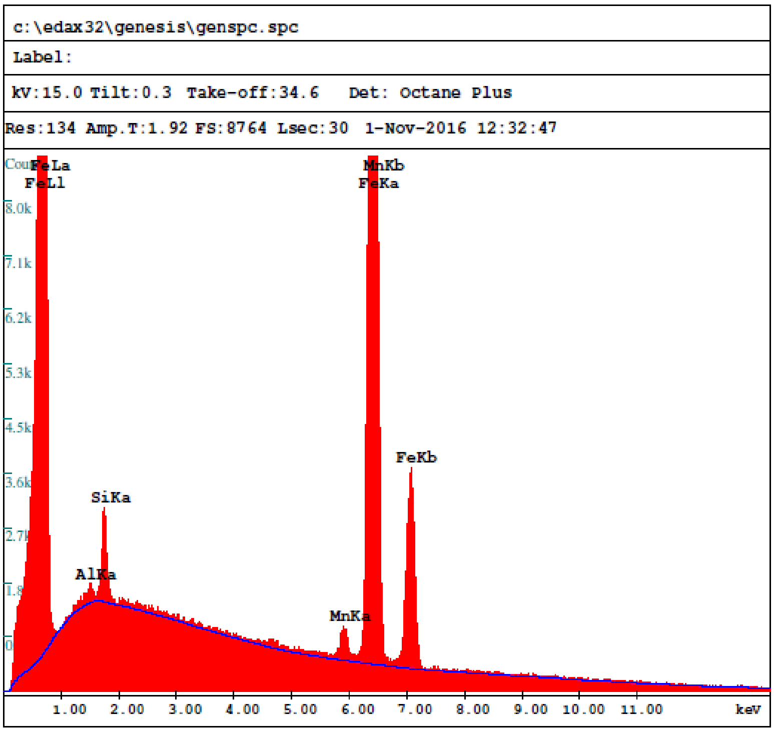


Picture no. 1 Graphical behaviour of dependence of absorbed energy on temperature change

Test of chemical composition of weld metal was realized according to Accredited test number of the test record 4353/2016 tab. no.4. Verification of chemical composition was also checked with the help of spectral composition - see picture no.2.

Identification of the test subject	Method	AES																	
	Standard	ASTM E 415-14																	
	Parameter	C	Mn	Si	P	S	Al	Cu	Ni	Cr	As	Ti	V	Nb	Mo	Co	Sn	B	Ca
	Unit	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
Base Material	Test result	0.137	0.654	0.241	0.013	0.009	0.033	0.042	0.026	0.061	0.002	0.002	0.001	<0.002	0.002	0.003	0.003	0.0003	0.0007
	U	±0.006	±0.013	±0.011	±0.002	±0.002	±0.002	±0.003	±0.002	±0.004	±0.001	±0.001	±0.001	-	±0.002	±0.002	±0.001	±0.0001	±0.0003
weld	Test result	0.074	1.239	0.698	0.012	0.009	0.002	0.017	0.017	0.014	0.005	0.002	0.002	<0.002	0.003	0.008	0.005	0.0012	<0.0002
	U	±0.004	±0.018	±0.024	±0.002	±0.002	±0.002	±0.002	±0.002	±0.002	±0.001	±0.001	±0.001	-	±0.002	±0.002	±0.001	±0.0002	-

Tab.4 Test of chemical composition of weld metal



Picture no. 2 Verification of chemical composition was also checked with the help of spectral composition

Values which are defined by standard EN ISO 14341-A, after comparison and verification in accredited test rooms (values $R_{eL\ min.}$ / $R_{p0,2\ min}$. = 420 [MPa], R_m = 500 up to 640 [MPa], A_{min} = 20 [%]), were in accordance with required ranges stated by standard. The same can be said about the values of impact test of the weld metal 47 J = -40 [°C]. Values, for maximal content of elements stated in weight percentage, for some elements were in required range.

C = 0.06-0.14, Si =0.5-0.8, Mn=0.9-1.3, P=0.025, S=0.025, Ni=0.15, Mo=0.15, Al=0.02, Ti+Zr=0.15, Cr=0.15, Cu=0.35 – required by standard

C = 0.008, ***Si =0.89*** *,* ***Mn=1.45,*** *P=0.019, S=0.013, Ni=0.14, Mo=0.14, Al=0.02, Ti+Zr=0.13, Cr=0.13, Cu=0.02 – values from attest*

C = 0.074, Si =0.69, Mn=1.23, P=0.012, S=0.09, ***Ni=0.17****, Mo=0.03, Al=0.02, Ti+Zr=- , Cr=0.014, Cu=0.017 –values from test room*

Verification of weld joint features during welding of tested samples for WPQR with the use of additional material according to EN ISO 14341-A: G 42 4 M21 3Si1

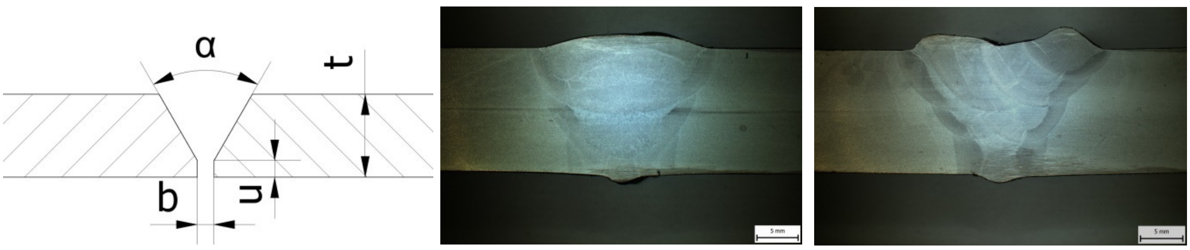
The test samples for the approval process were prepared from steel S355J2+N (classified into group 1.2) Chemical composition and mechanical features of these materials are presented in tab. 5.

S355J2+N according to EN 10027-1		**Values according to control record**	
Steel number according to EN 10027-2: **1.0577** Grading according to TNI CEN ISO/TR 15608: subgroup **1.2**		Inspection certificate according to EN 10204/3.1 Product standard EN 10025-2 Metal sheet 2000x12000 mm, thickness t = 15 mm	
R_{eH} = min. 355 MPa (≤16mm), R_m = 490-630 MPa A_5 = 22 % KV_{min} 27 J / -20 °C	$C_{max.}$ = 0.2 [%wgt.] $Si_{max.}$ = 0.55 $Mn_{max.}$ = 1.6 $P_{max.}$ = 0.035 $S_{max.}$ = 0.035	R_{eH} = 439 MPa R_m = 556 MPa A = 31 % $KV_{-20°C}$ = 148 J	C = 0.14 % [wgt.] Cr = 0.07 % Si = 0.21 % Mo = <0.006 % Mn = 1.22 % Cu = 0.04 % P = 0.012 % Ni = 0.26 % S = 0.002 % Al total = 0.028 % Ti, V = <0.005 Nb = 0.024 N = 0.008 CE = 0.39
Note: Chemical composition is stated according to melting			

Tab. 5 Chosen values of mechanical features and chemical composition of tested sample material

Geometry of weld joints and welding parameters

Welding edges of sheets were arranged in compliance with the type of joint and wall thickness. During geometry it is possible to use recommendation of EN ISO 9692 (Welding and similar processes. Recommendation for joint preparation), part 1 for methods 111, 13 and beam technology. Sheet edges chamfering and total geometry of joints with placing of weld passes for all test samples is shown in tab. 6. **Method A** (according to EN 1011-2) was used for calculating of the base material preheating temperature. For all test samples and welding conditions according to tab. 6 is the temperature calculated on level 0°C, so preheating is not necessary. Selected shape, diameters and method of placing layers for joints according to approved WPQR, are shown in picture no. 3. Macrostructures PF, PC are also shown there.



t = 15 mm; b = 2-3 mm; u = 2 mm, α = 60° *Welding position PF,* *PC*

no. 01, 02, 03

Picture no.2 Selected shape, diameters and method of laying up for weld joints according to WPQR

As parameters of welding are dependent in a large extend on welding position, we state only scale of heat input, which was moving in the range from 0,33 to 1,20 [$kJ.mm^{-1}$]. For comparison of mechanical features of weld joint are important for us: tensile test, breakdown test, impact test in bend, and hardness test. In tab. 6 Results of destructive test for butt joint, there are presented results of destructive tests for butt weld joint (Z-03). As butt joint has the thickness t = 15 mm, the lateral bend (test bar with identification SBB) was chosen for the breakdown test according to EN ISO 15614-1.

Tab. 6 Results of destructive tests for butt joint

Testing method	Tested body/ diameters of cross-section	Measured and calculated quantity (unit)	Measured values	Limit of evaluation	Test result
Tensile test in transverse direction (2 tested bars)	**t_s** x **b** 15x25 mm	Strength of breakage F_m [N] Tenacity in tensile force R_m [MPa]	R_m = 521 a 535 MPa *Fracture occurred in base material*	470-630 MPa (S355J2+N)	acceptable
Breakdown test in transverse direction (4 tested bars SBB)	**t_s** x **b** 10x15 mm **l** = 68 mm **d** = 40 mm	Occurrence of fractures and other damages after breakdown test in the area of root, and facial side of weld joint.	Without occurrence of fractures bigger than 3 mm	Fractures and other mistakes up to 3 mm	acceptable
Impact test in bend (3 tested bodies VWT 0/1 and 3 tested bodies VHT 1/1)	**h** x **w** x **h_o** 10x10x8 mm	Used up energy for breaking the body KV [J]	KV_{ZK} / -20 °C = 134, 114, 119 J KV_{strZK} = 122 J, KV_{minZK} = 114 J $0,7KV_{strZK}$ = 85 J KV_{TOO} / -20 °C = 47, 39, 47 J KV_{strTOO} = 44 J, KV_{minTOO} = 39 J $0,7KV_{strTOO}$ = 31 J	KVmin /-20 °C = 27 J (S355J2+N) And at the same time KVmin ≥ 0,7KVstr	acceptable

Notes to Tab. 6: Results of destructive test for butt joint
t_s – tested bar thickness, b – tested bar width
SBB – bar for breakdown test of butt joint from lateral side, l – distance between rollers, d – diameter of punch
VWT – sample for impact test in bend V: notch, W: notch in weld metal, T: notch perpendicularly to surface,
VHT – sample for impact test in bend V: notch, H: notch in heat affected zone, T: notch perpendicularly to surface,
h – height of tested body, h_o - height of samples under notch, w – width of tested body, ZK – weld metal, TOO – heat affected zone

Comment 1: *During tensile test in transverse direction the tested bar tensile tenacity must not be lower than corresponding specified minimal tenacity for base material, if not stated otherwise (article 7.4.2 EN ISO 15614-1).*

Comment 2: *During breakdown test the identified isolated mistake cannot be > 3 mm. Mistakes occurring on edges of test bar during testing are not taken into account (article. 7.4.3 EN ISO 15614-1).*

Comment 3: *Middle value of the three tested bars must meet required demands during impact test in bend. On each notch placing can be individual value lower than minimal middle value in case that it is not lower than 70 % of given value (article 7.4.5 EN ISO 15614-1).*

Comment 4*: If during tensile test on cross butt joint the base material breaks down, minimal specific tenacity of the base material must be reached. During break in weld metal must be identified break tension with respect of real cross-section of weld joint. Indentified middle break tension in cross-section of the weld joint must be equal or higher than 0,8 of the specified tenacity of the used base material (article 7.4.1.2 c) EN 1090-2).*

Comment 5: *During hardness test the limit values are presented in Table 2 standard EN ISO 15614-1 (article 7.4.6.)*

Mechanical features of weld joint were verified by breakdown tests in the range according to the type of weld joint. In Tab. 7 Results of hardness test HV10 for all tested weld joints, the results of hardness test are presented where average values for every metallurgical area from facial and also from root side were used with all three samples.

Comment to previous text:
According to EN ISO 15614-1 the hardness test HV10 is required. In this case the distance of individual puncture must be min. 1mm. With smaller thickness of weld joints this rule is not possible to apply. It is desirable to lower the load (HV5, HV1) a in such way make the size of puncture smaller, as well as minimal distance of two punctures. In such way lowered load according to application standards comes under micro-hardness test and it is necessary to mention this fact into record.

Tab. 7 Results of hardness test HV10 for all tested weld joints

Test sample	**Area of weld joint/ average value of three measurements HV 10**					**Material**	**Group**	**Heat processing**	**Limit HV 10**
	ZM 1	TOO	ZK	TOO 2	ZM 2				
----	209	270	239	249	199	S355J2+N	1.2	No	380

Notes: ZM 1, ZM 2 – base material, TOO 1, TOO 2 – heat affected zone, ZK- weld metal

In case of meeting the requirements stated in standard EN ISO 15614-1 (conditions for welding of test samples, scale of testing and satisfactory results of individual tests) it is possible to apply the approved process for weld joints in the range stated in standard EN 15614-1.

CONCLUSION AND RESULT EVALUATION

The article was written in order to point out demands of additional materials quality requirements. Selection of additional materials is very important part of welding process. Considering the given group of material 1.2 the selection follows the similarity to welded material in the area of chemical composition and to mechanical features. Verification the features in comparative tests proved that the values are in required limits in accordance with standard EN ISO 14341-A.

It is also necessary to realize that in test qualification for example for WPQR it is not such a matter of course to reach the required results. Mainly it can be said in case of impact test in bend and in values of hardness, which are to a large extend influenced by welding parameters, welding position and thermal mode.

LITERATURE

[1] LEŽDÍK, V. – MIČIAN, M. – PATEK, M. (2016): *Schvaľovanie postupov zvárania kovových materiálov a plastov*, 205 s., Inštitút kvality a vzdelávania, s.r.o., Žilina VŠ učebnica

[2] Koukal, J. – Schwarz, D. – Hajdík, J. (2009) Materiály a jejich svařitelnost. Český svářecký ústav s.r.o. Ostrava, 1. Vyd. 2009, Ostrava, 241s. ISBN978-80-248-2025-5

[3] Kolektív autorov (1999) Materiály a jejich svařitelnost. Nakladatelství ZEROSS, Ostrava, 1999. 295s. IBN 80-85771-63-2.

[4] EN ISO 14341-A Svařovací materiály. Drátové elektrody a vytavené svárové kovy na obloukové svařování tavící se elektrodou v ochranném plyne nelegovaných a jemnozrnných ocelí.