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Application Regarding the Butt-Welding Through Intermediate Melting

It consists in presenting butt welding procedure through intermediate melting and its usage for manufacturing cutting tools type drill, tap screw, reamer by welding the active part (made of high-speed steel) to the tool tail (made of unalloyed steel wit low carbon).

1. Theoretical considerations regarding the welding through intermediate melting

Welding procedure schematic diagram is shown in figure 1.

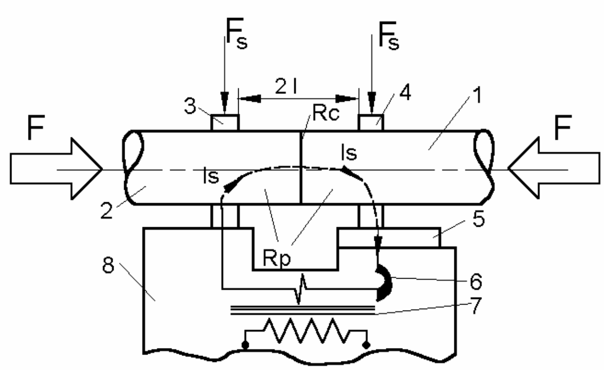


Figure 1. Electric welding schematic diagram through butt pressure.

1,2 – components for welding; 3 –immobile tightening device; 4 – mobile tightening device; 5 – mobile sledge; 6 – elastic element; 7 – transformer secondary; 8 – welding machine body.

The welding components 1 and 2 are fastened in the tightening devices 3 and 4, in such a way that a distance 2l should remain between them.

One of these tightening devices is immobile and the other is mobile so that they allow a variable distance between the front heads of the components to be welded. Also by means of the tightening devices the components to be welded are connected to the welding transformer secondary, that strongly decrease the voltage.

The welding operation is performed such as: the front surfaces of the components are brought in contact on their whole section. In order to maintain a contact between the heads of the welding components by means of the mobile sledge, a force F_S is applied in their axis direction. By connecting the electric power, the heads of the components are heated by Joule – Lenz effect. When the desired heat is reached, which is always lower at this welding procedure than the temperature of the material to be welded, a force $F_R > F_S$ called repressing force is applied to the components. As a consequence of the plastic deformation taking place within the contact area, the components get welded. The electric power is disconnected after a plastic deformation has taken place, and before exceeding a certain temperature, the both limits being determined by the dimensions and the material of the components to be welded.

Intermediate melting welding, with pre-heating is performed according to the diagram in figure 2.

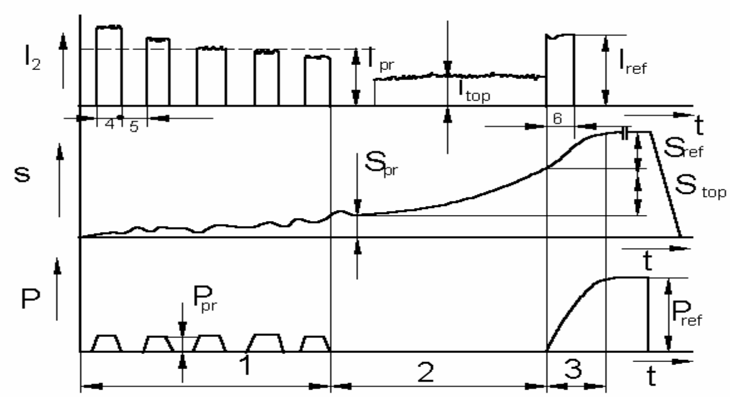


Figure 2. Variation of parameters P, s, I_2 at intermediate melting welding with pre-heating.

Before melting, the preheating is performed through electric pulses during the interval of time 1, intervals of load 4, it alternates with intervals of pause 5, the average current being adjusted for the value I_{pr}. During pre-heating, the force required for the contact of the heads rises up to the value P_{pr}. The process unfolds then similarly in the same way like the direct melting welding, with repressing under power during the period of time 6.

The parameters of the butt welding under pressure through intermediate melting with preheating can be classified in:

material parameters:
type of material;
chemical composition;
mechanical characteristics;
electrical characteristics;
geometrical parameters:
components diameter: d[mm];
shrinkage at melting: $S_{tmelt} = (0,5 \div 0,6) \cdot d$ [mm]; (1)
shrinkage at repressing: $S_{ref} = (0,15 \div 0,30) \cdot d$ [mm]; (2)
final free length of the components: $2l_f = (1 \div 2) \cdot d$ [mm]; (3)
initial free length of the components: $2l = 2l_f + S_{top} + S_{ref}$ [mm]; (4)
mechanic parameters:
force of repressing: $F_{ref} = p_{ref} \cdot A$ [N], (5)
where: p_{ref} = specific pressure of repressing:
$p_{ref} = 80 \div 100$ [Mpa] – for steel.
A – Area of the transversal section of the components:

$$A = \frac{\pi \cdot d^2}{4} \left[mm^2 \right]. \quad (6)$$

Force of melting: $F_{melt} = p_{melt} \cdot A$ [N], (7)
P_{melt} – specific pressure at melting:

$$P_{melt} \approx \frac{1}{10} \cdot p_{ref} \; ; \quad (8)$$

force of pre-heating: $F_{pr} = p_{pr} \cdot A$ [N], where: (9)
p_{pr} – specific pressure of pre-heating:

$$p_{pr} \approx \frac{1}{2} \cdot p_{ref} \quad (10)$$

force of tightening of components in device: $F_{str} = (1,5 \div 2)F_{ref}$. (11)
Electric parameters:
Intensity of the electric repressing current: $I_{ref} = j_{ref} \cdot A$ [A], where:
j_{ref} - density of current in the repressing stage;

j_{ref} = (15 ÷30) [A/mm^2] – for steel.

Intensity of the melting electric current: $I_{melt} = j_{melt} \cdot A$ [A], where: (12)

J_{melt} - density of current in the melting stage;

$$J_{melt} = \frac{1}{2} \cdot j_{ref} \quad (13)$$

Intensity of the pre-heating electric current: $I_{pr} = j_{pr} \cdot A$ [A] (14)

j_{pr} – density of current at pre-heating;

$$j_{pr} \approx \frac{2}{3} \cdot j_{ref} \quad (15)$$

the voltage on the front surfaces in contact:

in the melting stage:

$U_{ft} = I_{melt} \cdot R_C$, [V], where (16)

I_{melt} [A] – intensity of the melting current;

$$R_C = \frac{r_k}{F_{top}^{\alpha}} [\Omega], \quad (17)$$

r_k = 0,004 ÷ 0,006 [Ω daN] – for steel

F_{melt}= melting force [daN];

α = 0,25 – for steel;

in the repressing stage: $I_{ref} = I_{ref} \cdot R_C$ [V], where:I_{ref} [A], (18)

$$R_C = \frac{r_k}{F_{ref}^{\alpha}} [\Omega] \quad (19)$$

Secondary electric voltage, U_2

in the melting stage: $U_{2t} = (1{,}3 \div 1{,}4) \cdot U_{ft} [V]$ (20)

in the repressing stage : $U_{2r} = (1{,}3 \div 1{,}4) \cdot U_{ref} [V]$ (21)

- maximum electric power: $P_{2\,max} = \max(U_{2t} \cdot I_{melt}; U_{2r} \cdot I_{ref})$ [kVA] (22)

parameters of time:

velocity of melting : $V_{melt} \equiv V_b$, during melting, the following relation should be observe:

$$U_{ft} \geq \frac{c \cdot \gamma}{\eta} \cdot R_C \cdot V_b \cdot A\left(T_{top} - T_0\right) \Rightarrow V_{top} \leq \frac{U^2{}_{ft} \cdot \eta}{c \cdot \gamma \cdot R_C \cdot A\left(T_{top} - T_0\right)} \quad (23)$$

it is low at the beginning of melting when R_C is high and the difference ($T_{melt} - T_0$) is high and 2 ÷ 4 higher at the end of melting when the difference ($T_{melt} - T_0$) is low.

The time of melting is t_{melt} :

$$t_{melt} = \frac{S_{top}}{V_{topmed}} \tag{24}$$

velocity of repressing:
$V_{ref} = (5 \div 10) \times V_{melt\ max}$;
Time of repressing under power:

$$t_{ref\ c} = \frac{S_{ref.c}}{V_{ref}} \tag{25}$$

time of repressing without current:

$$t_{reffc} = \frac{S_{reffc}}{V_{ref}} \tag{26}$$

time of pre-heating:

$$t_{pr} = 0,5 \div 4 \text{ [sec]}.$$

2. Experimental researches regarding the butt welding through intermediate melting of the cutting tools

The methodology of experimental optimization of the analyzed welding regimes through intermediate melting.

The elaboration of a welding technology presumes to determine certain numerical values for each parameter of the welding regime.

Practically, there is an endless number of possibilities to perform a part using this method from the technological point of view.

That's why, the optimization of this activity represent an essential matter, i.d. the determination of the best technological decision depending on one or more criteria taken into consideration. The optimization consists in establishing the welding regime for which the respective criterion or criteria have a maximum or minimum value.

An indirect method will be used for optimization, called the method of gradient.

Experimental optimization of the welding regimes through intermediate melting of the cutting tools

Parameters of the welding regime are established such as:

Parameters of material

The basis materials were:

For the tool tail – carbon steel type OLC 15 – STAS 800 – 80 ;

For the active portion of the tool – high-speed steel type Rp3 – STAS 7382/ 80;

Among the physical properties, those that influence the welding process by intermediate melting are the electric properties :

Electric resistivity;

Temperature coefficient of the electric resistivity. They are:

for OLC 15 : $\rho_0 = 0,2$ [$\Omega \times mm^2/m$]; $\alpha_g \approx 5\times10^{-3}$ [1/°C];

for Rp 3 : $\rho_0 = 0,9$ [$\Omega \times mm^2/m$]; $\alpha_g \approx 2\times10^{-3}$ [1/°C];

Geometrical parameters:

Diameter of test samples used for experiments: d =5; 10; 15 [mm];

Shrinkage at melting, s_{melt} (it is determined for the milder steel – OLC 15):

$$s_{melt} = (0,5 \div 0,6) \times d \approx 0,5 \times d . \qquad (27)$$

It results: s_{melt1} = 2,5 [mm]; s_{top2} = 5 [mm]; s_{top3} = 7,5 [mm];

Shrinkage at repressing :

$$S_{ref} = (0,15 \div 0,30) \times d \approx 0,2 \times d \qquad (28)$$

It results: $s_{ref\ 1}$ = 1 [mm]; $s_{ref\ 2}$ = 2 [mm]; $s_{ref\ 3}$ = 3 [mm];

Shrinkage at repressing under power:

$$s_{ref\ c} = 0,5\times s_{ref} \qquad (29)$$

It results: $s_{ref\ c}1 = 0,5\times 1 = 0,5$ [mm] $s_{ref\ c}2 = 0,5\times 2 = 1$ [mm];

$s_{ref\ c}3 = 0,5\times 3 = 1,5$ [mm]

Final free length, $2l_f$ (it is separately determined l_f for each material):

for OLC 15: $l_1 = (0,5 \div 1)\times d \approx 0,8 \times d$; (30)

It results: $l_{11} = 0,8 \times 5 = 4$ [mm]; $l_{12} = 0,8 \times 10 = 8$ [mm]; $l_{13} = 0,8 \times 15 = 12$ [mm];

for Rp 3, l is correlated with the electric resistivity of the material to be welded. In order to perform a uniform heating of the components the following relation is used:

$$l_{OLC\ 15} \times \rho_{0\ OLC\ 15} = l_{Rp\ 3} \times \rho_{0\ Rp\ 3} \qquad (31)$$

It results $l_{21} = l_{11} \times 0,2/0,9$; $l_{22} = l_{12} \times 0,2/0,9$; $l_{23} = l_{13} \times 0,2/0,9$;

$l_{21} = 4 \times 0,2/0,9$; $l_{22} = 8 \times 0,2/0,9$; $l_{23} = 12 \times 0,2/0,9$;

l_{21} = 0,88 [mm]; l_{22} = 1,77 [mm]; l_{23} =2,66 [mm];

It results: $2l_{f1} = l_{11} + l_{21} = 4 + 0,88 = 4,88$ [mm]; (32)

$2l_{f2} = l_{12} + l_{22} = 8 + 1,77 = 9,77$ [mm];

$2l_{f3} = l_{13} + l_{23} = 12 + 2,66 = 14,66$ [mm];

initial free length, $2l_I$: $2l_I = 2l_f + s_{melt} + s_{ref}$ (33)

$2l_{i1} = 2l_{f\ 1} + s_{melt\ 1} + s_{ref\ 1} = 4,88 + 2,5 + 1 = 8,38$ [mm];

$2l_{i2} = 2l_{f\ 2} + s_{melt\ 2} + s_{ref\ 2} = 9,77 + 5 + 2 = 16,77$ [mm];

$2l_{i3} = 2l_{f\ 3} + s_{melt\ 3} + s_{ref\ 3} = 14,66 + 7,5 + 3 = 25,16$ [mm];

Mechanical parameters:

Force of repressing, $F_{ref} = p_{ref}\times A$ [N],where: p_{ref} = 100 [Mpa]; $A = \pi\times d^2/4$; (34)

It results : A_1= 19,6 [mm^2]; A_2= 78,5 [mm^2]; A_3= 176,6 [mm^2]; $F_{ref\ 1}$ = 1960 [N] = 196 [daN]; $F_{ref\ 2}$ = 7850 [N] = 785 [daN]; $F_{ref\ 3}$ = 17660[N] = 1766 [daN];

Force of melting, $F_{melt} \approx 1/10 \times F_{ref}$ [N]; (35)

$F_{melt\ 1}$ = 19,6 [daN]; $F_{melt\ 2}$ = 78,5 [daN]; $F_{melt\ 3}$ = 176,6 [daN];

Force of preheating, $F_{pr} \approx ½ \times F_{ref}$: (36)
$F_{pr\,1}$ = 98 [daN]; $F_{pr\,1}$ = 392,5 [daN]; $F_{pr\,1}$ = 883 [daN];
Force of tightening of the components in device, $F_{str} \approx 2\times F_{ref}$:
$F_{str\,1}$ = 392 [daN]; $F_{str\,1}$ = 1570 [daN]; $F_{str\,1}$ = 3532 [daN];
Electric parameters:
Intensity of the electric current in the repressing stage, I_{ref} :
$I_{ref} = j_{ref} \times A$ [A], where: $j_{ref} \approx 20$ [A/mm^2]; (37)
$I_{ref\,1} = 20 \times A_1 = 20 \times 19.6 = 392$ [A]; $I_{ref\,2} = 20 \times A_2 = 20 \times 78,5 = 1570$ [A];
$I_{ref\,3} = 20 \times A_3 = 20 \times 176,6 = 3532$ [A];
Intensity of the electric current in the melting stage, I_{melt} : $I_{melt} \approx ½ \times I_{ref}$ (38)
$I_{melt\,1}$ = 196 [A]; $I_{melt\,2}$ = 785 [A]; $I_{melt\,3}$ = 1766 [A];
Intensity of the electric current in pre-heating stage, I_{pr} : $I_{pr} \approx 2/3 \times I_{ref}$ (39)
$I_{pr\,1}$ = 261 [A]; $I_{pr\,2}$ = 1047 [A]; I_{pr3} = 2355 [A];
Electric voltage on the surfaces in process of melting, U_{ft} : $U_{ft} = I_{melt} \times R_c$ [V],
where:$R_c = r_k/F^{\alpha}_{top}$ [Ω]; $r_k \approx 0,005$ [$\Omega\times$daN]; α= 0,25. (40)
$U_{ft\,1} = 196 \times 0,005/19,6^{0,25} \approx 0,4$ [V]; $U_{ft\,2} = 785 \times 0,005/19,6^{0,25} \approx 1,6$ [V];
$U_{ft\,3} = 1766 \times 0,005/19,6^{0,25} \approx 3,6$ [V];
Voltage on the surfaces during repressing, $U_{fr} = I_{ref} \cdot R_c$ (41)
$U_{fr\,1} = 392 \cdot 0,005/196^{0.25} \approx 0,5$ [V]; $U_{fr\,2} = 1570 \cdot 0,005/196^{0.25} \approx 2$ [V]
$U_{fr\,3} = 3532 \cdot 0,005/196^{0.25} \approx 5$ [V]
Power consumed at melting: $P_{melt} = (1,3\div1,4)U_{ft} \cdot I_{melt}$ [W] (42)
$P_{melt\,1} = 1,3 \cdot 0,5 \cdot 196 = 127$ [W]; $P_{melt\,2} = 1,3 \cdot 2 \cdot 785 = 2041$[W];
$P_{melt} = 1,3 \cdot 5 \cdot 1766 = 11479$[W]
Power consumed at repressing :$P_{ref} = (1,3\div1,4)\, U_{fr} \cdot I_{ref}$ (43)
$P_{ref1} = 1,3 \cdot 0,5 \cdot 392 = 254$ [W]; $P_{ref\,2} = 1,3 \cdot 2 \cdot 1570 = 4082$[W];
$P_{ref\,3} = 1,3 \cdot 5 \cdot 3532 = 22958$[W]
Parameters of time:
Power required for welding, $P_{max} = P_{ref}/\eta$, where η- process efficiency, (44)
η = 0,7.$P_{max\,1}$ = 363 [W]; $P_{max\,1}$ = 5831 [W]; $P_{max\,1}$ = 32797 [W];
Velocity of welding : $V_{melt} = V_b = P_{max}/c\cdot\gamma\cdot A\cdot(T_{melt}-T_0)$, where: $T_{0\,1}=T_{pr}\approx600$[°C]
$T_{0\,2} \approx 1500$[°C] $T_{top}\approx1700$[°C]; c =0,11·4,186 [J/g·°C] γ=7,85
$V_{melt\,min\,1}$ = 363/0,11·4,186·19,625·7,85(1700-600)= 0.0044 [mm/s]
$V_{melt\,min\,2}$ = 5831/0,11·4,186·78,5·7,85(1700-600)= 0,018 [mm/s]
$V_{melt\,min\,3}$ = 32797/0,11·4,186·314·7,85(1700-600)= 0.028[mm/s]
$V_{melt\,max\,1}$ = 363/0,11·4,186·19,625·7,85(1700-1500)= 0,025[mm/s]
$V_{melt\,max\,2}$ = 5831/0,11·4,186·78,5·7,85(1700-1500)= 0,102 [mm/s]
$V_{melt\,max\,3}$ = 32797/0,11·4,186·314·7,85(1700-1500)= 0.14 [mm/s]
Velocity of repressing , $V_{ref} \approx 10 \cdot V_{melt\,max}$: (45)
$V_{ref\,1}$ =0,25 [mm/s]; $V_{ref\,2}$ =1,02 [mm/s]; $V_{ref\,3}$ =1,4 [mm/s];

Time of melting, $t_{top} = s_{top} / V_{top\ med}$ (46)
$t_{melt\ 1}$ =2,5/0,021= 116,21 [sec]; $t_{melt\ 2}$ =5/0,065= 77 [sec];
$t_{melt\ 3}$ =7,5/0,084= 89 [sec]; time of repressing, $t_{ref} = s_{ref} / V_{ref}$: (47)
$t_{ref\ 1}$ = 1 / 0,25=4 [sec]; $t_{ref\ 2}$ = 2 / 1,02=2 [sec]; $t_{ref\ 3}$ = 3 / 1,4=2,14 [sec].

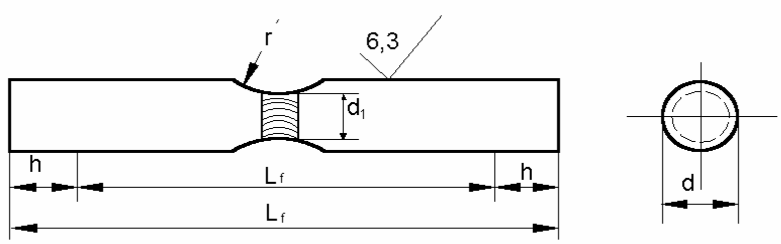
Time of repressing under power, $t_{ref\ c} = s_{ref\ c} / V_{ref}$: (48)
$t_{ref\ c\ 1}$ = 0,5/ 0,25= 2 [sec]; $t_{ref\ c\ 2}$ = 1/ 1,02= 0,98 [sec]; $t_{ref\ c\ 3}$ = 1,5/ 1,4= 1,07 [sec];

The resistance at longitudinal traction was the optimisation criterion chosen, with the respect of its maximization, according to STAS 5540/2 - 82

The test sample shape and dimensions are indicated in fig. 4 and table 1 for round samples with reduced section near the welding. The samples are cut perpendicularly on the weld so that it should pe positioned in the middle of the portion with diminished section. The longitudinal axis of the weld should be placed in the transversal plane of symmetry of the sample. The test performing: according to the national standards of loading at traction. The load is applied on a perpendicular direction to the welding axis until braking. The velocity of loading should be as constant as possible. Result expressing: The braking resistance of the weld is calculated with the relation:

$$R_m = \frac{F_{\max}}{S_0} \qquad (49)$$

R_m – resistance against braking [N/mm^2];
F_{max} – maximum load suffered by the sample [N];
S_0 – The area of the minimum initial section of the sample in the reduced section.



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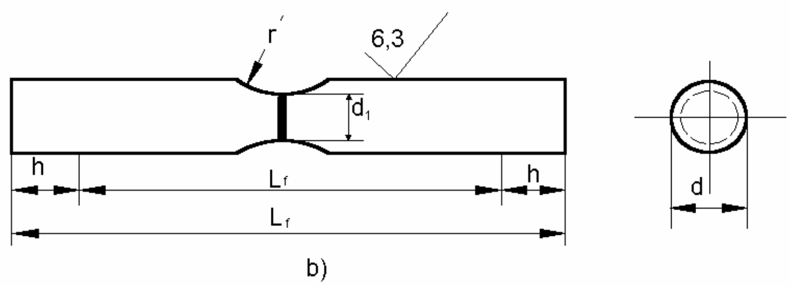

Figure 3. Sample shape and dimensions subject to the traction test

- samples diameter, d = 5;10;15 [mm];
- total length, L_t= 250 [mm];
- width of the portion with reduced section, d_1 = 0,6d;
- minimum width of the fastening head, h = d;
- roundness ray of the reduced section, r = 0,5d.

These parameters of the welding regime were subsequently optimised experimentally according to the presented methodology. After 45 regimes, the following optimal regimes resulted (table 1):

Table 1

No. crt.	Parameters of the welding regime	d=5 [mm]	d=10 [mm]	d=15 [mm]
1	s_{melt} [mm]	2	4,5	7
2	s_{ref}[mm]	1,5	2	3
3	$s_{ref\ c}$[mm]	0,6	0,8	1,1
4	$2l_{f1}$[mm]	5	10	15
5	$2l_l$[mm]	8,5	16,5	25
6	F_{ref} [daN]	200	800	1800
7	F_{melt} [daN]	21	82	185
8	F_{pr} [daN]	100	400	900
9	F_{str} [daN]	400	1600	3600
10	I_{ref} [A]	400	1600	3600
11	T_{pr} [°C]	550÷600	550÷600	550÷600
12	I_{pr} [A]	300	1100	2300
13	U_2 [V]	0,7	3	6

15	t_{melt} [sec]	120	80	90
16	t_{ref} [sec]	4	2	3
17	$t_{ref\ c}$ [sec]	2	1	1

3. Results of researches

According to the data in the table 2.

Table 2

Parameters → Components diameter ↓	Force of braking at traction [daN]	Resistance of braking against traction [Mpa]
5 [mm]	613	312
10 [mm]	2435	310
15 [mm]	5620	318

4. Conclusions

The free length of the active portion is smaller than that of the cutting tool tail.

The high-speed steel was found out to melt faster than the carbon steel, the values of the shrinkage during melting being corrected during the experiments.

After the weld has been performed, a heating treatment of the welded join was needed by heating in furnace at 740 ÷760 [°C], for approximately 6 hours and slow cooling in the same time with the furnace.

The mechanical resistance of the join was within the limits of the mechanical resistance of the drill tail material.

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