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CONSIDERATIONS REGARDING THE INFLUENCE OF STRESS RELIEVING BETWEEN PASSES IN MULTI-LAYER WELDING ON THE SIZE OF ACTIVE INPUT ENERGY

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ABSTRACT

From the quality point of view, it is generally known the fact that, in multi pass welding one can count on the reduction of stresses and majority of residual strains. The paper presents an analytical-experimental methodology to quantitatively assess this effect. In this purpose the white method is used to determine the size of plasticized area when welding (which is necessary to control residual stresses) and the general calculus method of stresses and residual strains (Okerblom). The direct result consists of the analytical evaluation of the active input energy (the calculus one) when using multi-layer welding. Knowing this size is necessary to calculate all types of welding stresses and strains using the general calculus method. The advantage of applying these methodologies consists of keeping compression residual strains under a certain imposed level.

1. CALCULATING METHODS OF THE RESIDUAL STRESSES IN MULTI PASS WELDING

Multi pass welding produces a partial remelting of the layers that have been previously deposited and have a certain de-tension. The theoretical assess of the residual stresses in welding is complicated in this situation because the linear active energy is not the amount of the linear energies that are used for every pass. This also applies for the residual stresses in welding. Thus, the concept of linear calculus energy (active linear energy) appeared. If this is evaluated precisely enough, we can count, in the following steps, on using the calculus relations known in the case of the single passing welding [1]…[6]. The distribution of the strains in section does not modify, in principle, compared to the single passing weld and is presented in figure 1.

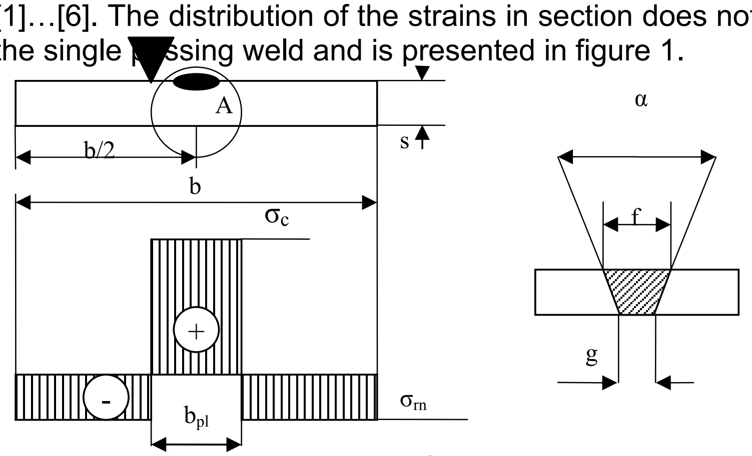

Fig. 1 Linear distribution of the longitudinal residual stresses in the section V-type welded piece, disposed axial centric

The following notations are used:

b = piece's width
s =piece's thickness
b_{pl} =the width of the plasticized area at welding
σ_c =yield limit (positive residual stresses, or traction)
σ_{rn} =negative residual stresses (or compression)
α = slope angle of the groove
f, g =groove dimensions

In the case of welding plates with a V-type joint, a general method for the calculus of stresses and residual strains, or the Okerblom method, allows solving the determination of the active input energy and the contraction residual stresses.

Presuming that we know the input energy used for a single pass, the following relations are applied successive:

$$r_{pl} = 21{,}31 \cdot 10^{-3} \cdot \sqrt{q_l}; \quad (1)$$

$$q_{lc} = 1421\left(A_r + \frac{2 \cdot r_{pl} \cdot s}{\cos\frac{\alpha}{2}} \right); \quad (2)$$

$$A_{pl} = \frac{1}{\frac{1}{A} + \frac{1421}{q_{lc}}}; \quad (3)$$

$$\sigma_{rn} = E \cdot \mu \cdot q_{lc} \cdot \frac{1}{A}; \quad (4)$$

, where:
r_{pl} =plasticization radius
q_1 =input energy for welding a single pass
q_{1c} =linear calculus energy
A_r =area of the commissural
A_{pl} = area of the plasticized zone
A = area of the transversal section of the piece
E =longitudinal elastic modulus
μ =material coefficient ($-0.85 * 10^{-6} cm^3 / J$ for usual construction steels)

A more modern calculus method is the White method [7], [8]. This method does not use explicitly the linear calculus energy concept, but uses the concept of "tendon force"; by this meaning the force that balances the residual stresses distributed in the all piece section.

In this method, for determining the negative residual stresses (the positive one is always the yield limit) an original calculus algorithm is used [9]. Being less known is considered helpful to present and evaluate this algorithm.

The steps of this algorithm are:

1. An initial calculus for the value of $\sigma_{rn}(i)$ is proposed;
2. The plasticized area is calculated with the relation:

$$A_{pl} = \frac{F_t}{\sigma_c + |\sigma_{rn}|} \quad (5)$$

where F_t = "tendon force"=2* q_1 (initially);

3. The "tendon force" is reevaluated:

$$F_t = (\sigma_c + \sigma_{rn})\left(1{,}6 \cdot s \cdot \sqrt{A_{pl}} + A_r\right); \qquad (6)$$

4. The residual stress is recalculated:

$$\sigma = -F_t / A; \qquad (7)$$

5. The obtained (σ_{rn}) value is compared to the one proposed initially. If the values are almost the same, we consider the problem solved. If not, the algorithm is repeated from step no. 2.

Case study:

We consider a piece made of S235 (OL37) sheet that has the following geometrical characteristics: b=300, s=15, α=50, g=3, f=17, A=45 cm^2, A_r=1.5 cm^2. The axial centric weld is made using 5 passes with the MAG procedure in horizontal weld position. Medium input energy, calculated for every pass is q_1=12481J/cm. It is initially proposed $\sigma_{rn} = -300 dan/cm^2$.

The obtained results are presented in table 1 and qualitatively in figure 2.

Table 1. Intermediary and final results for "case study"

Measure	White Method					Okerblom Method
	The Step of the Algorithm					
	1	2	3	4	5	
σ_{rn}(i)[daN/cm^2]	-300	-411	-338	-328	-326	-
A_{pl}[cm^2]	9,25	6,57	5,56	5,41	**5,38**	**7,76**
F_t[daN]	18475	15221	14761	14675	14660	-
σ_{rn}[daN/cm^2]	-411	-338	-328	-326	**-326**	**-529**

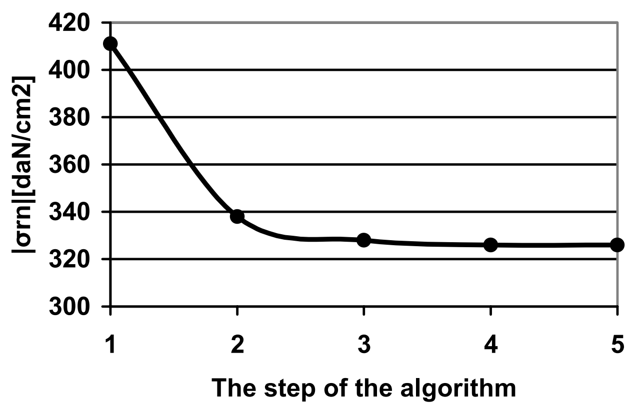

Fig. 2 The qualitative evolution of the residual stresses calculus σ_{rn} according to the steps of the algorithm, for the analyzed example

Findings:

-the algorithm is fast-convergent

-the Okerblom method is more comprehensive compared to the White method; because of the larger plasticized area resulted after the calculus;

-for now, it is not clarified the problem of determining the input energy of calculus (active) according to the principles of the White method.

2. ANALYTICAL- EXPERIMENTAL METHODOLOGY OF DETERMINING THE MAXIMAL PASSING NUMBER AT WELDING

Analyzing the theoretical basis of the two calculus methods that have been presented, we can see that neither one of them takes under direct consideration the number of welding passes. The explanation for this situation is the degree of difficulty; the real situations can always be varied.

The simplest exit from this dead end is the use of the experience accumulated in this domain which offers solutions that are verified practically when choosing the number of welding passes (n_t).

An example of such a case is represented also by the selected data in table 2, according to [10].

Table 2. Technological parameters for the MAG welding of carbon and low-allied steel – butt welding

Tehnological Welding Parameters	s[mm]						
	5	6	8	10	12	**15**	20
α[°]	50	50	50	50	50	**50**	50
g[mm]	2	2	2	2,5	2,5	**3**	3
n_t	**2**	**2**	**3**	**3**	**4**	**5**	**10**
v_s[cm/min]	r 23 u 47,5 t -	r 29 u 33 t -	r 19,5 u 66 t 59,5	r 20 u 40 t 32	r 22 2u 37 t 36	**r 16,5 3u 33,5 t 22**	r 14 9u 50,5 t -
I_s[A]	r 125 u 200 t -	r 125 u 205 t -	r 137 u 270 t 270	r 135 u 290 t 290	r 135 u 190 t 190	**r 130 u 300 t 300**	r 140 u 310 t -
U_a[V]	r 18,5 u 21,0 t -	r 18,5 u 21,5 t -	r 18 u 27,5 t 27,5	r 18,5 u 28 t 28	r 18,5 u 28 t 28	**r 18,5 u 28,5 t 28,5**	r 19 u 29 t -

Primary observations:

-commissural opening angle is constant (α=50º);

-commissural opening at its root varies slightly (g=2…10mm);

-the number of passes varies significantly (n_t=2…10) with the components thickness.

-the close and also low values for Is and Ua corroborated with the low welding speeds indicate the necessity of some special precautions for a root pass, precautions that need to be maintained;

-in the places where the brush passes are missing it is presumed that the filling pass must ensure a corresponding exterior aspect as well for the weld.

In order to find easier the possibilities to have a higher number of passes, we must analyze the situation of the linear input energies that result using the primary technological parameters that are recommended. This is presented in table 3, with the notice that the value $\eta = 0.8$ has been adopted for the effective heat transfer of the electrode arc-piece.

Table 3 also presents the total input energies required for the realization of the filling and exterior layers that will be marked as q'_{lt} in the following section.

Table 3. Input calculated energies, generally recommended

s[mm]	5	6	8	10	12	15	20

n_t	2	2	3	3	4	5	10
q_l[J/cm]	r 4826	**r 3826**	r 5982	r 5977	r 5449	r 6996	r 9120
	u 4244	u 6411	u 5400	u 9744	2u 6902	3u 12251	9u 8545
	t -	t -	t 5990	t 12180	t 11083	**t 18655**	t -
q'_{lt} [J/cm]	4244	6411	11390	21924	24887	55408	76905

Secondary observations (after analyzing the data in table 3):

-the recommendable values for the input energies are between 3800…18700 J/cm;

-minimal input energy, agreed for the realization of a filling layer, that can have the role of exterior layer after all, is of approximately 4200 J/cm; this value will be marked as q^*_{lu};

-if it is accepted that the technological parameters for the realization of the root remain unmodified, it results that for the 5 and 6 mm thickness of the sheet metal, it is not rational to increase the number of passes.

The determination of the recommendable maximal pass number is realized now expediently.

$$n_{t\max} = q'_{lT} / q^*_{lu}. \tag{8}$$

The systematization of the resulted situation is presented in table 4.

Table 4. Input energies for a maximum welding pass number (technically motivated acceptable)

n_t	8	10	12	15	20
n_t	4	6	7	14	19
q_l[J/cm]	r 5982	r 5994	r 5449	r 6996	r 9120
	3u 3797	5u 4385	6u 4148	13u 4262	18u 4273

In a similar way we can operate in any situation of interest where there is a welding technology in the technical literature.

3. THE DECREASE OF THE WELDING ACTIVE INPUT ENERGY WITH A MAXIMAL NUMBER OF PASSES

For the quantitative quantification on analytical-experimental basis of the influence of the stress relaxation between passes over the tensions measures, and even in case of the majority of the residual strains in welding, we must look at the two situations (combining the number of passes– input energy/ pass) previously presented:

-the usual residual situation (table 3) variant that will be marked as V_1 in the following presentation;

-the situation defined through a maximal number of passes (table 4) variant that will be marked as V_2.

This quantitative quantification is achieved based on the evident differences for the size of the input energy (of calculus) in welding, with the formula:

$$\Delta\% = 100 - \frac{q_{lc}(V_2)}{q_{lc}(V_1)} \cdot 100[\%]. \tag{9}$$

Using the earlier obtained data and also the relations (1) and (2) offered by the Okerblom method the values presented in table 5 are obtained.

Table 5. Intermediary calculus and the percent estimation (Δ) regarding the decrease of the active input energy at welding with a maximum number of passes

s[mm]	8	10	12	15	20
A_r[cm2]	0,47	0,72	0,97	1,5	2,46
q_{lT} (*)[J/cm]	17372	27918	30336	62404	86025
Usually reccomended situation (V_1)					
n_t	3	3	4	5	10
$q_{l\ med}$[J/cm]	5791	9306	7584	12481	8603
r_{pl}[cm]	1,62	2,06	1,86	2,38	1,98
q_{lc}[J/cm]	4738	6469	8388	13343	15932
Situation defined by $n_{t\ max}$ (V_2)					
Tab. 5 (continued)					
n_t	4	6	7	14	19
$q_{l\ med}$[J/cm]	4343	4653	4334	4457	4528
r_{pl}[cm]	1,4	1,45	1,4	1,42	1,43
q_{lc}[J/cm]	4185	5577	6654	8821	12477
Δ[%]	11,7	13,8	20,7	33,9	21,7

* q_{iT} =total input energy used at welding (the amount of input energies used for every pass).

In this table, the notation q_{1med} is read as the medium input energy when one weld layer is made. The calculus for this energy uses the next formula:

$$q_{lmed}(V_1) = \frac{1}{n_t}\left(q_{lr} + \sum_{i=2}^{n_t} q_{lu_i}\right), \quad (10)$$

$$q_{lmed}(V_2) = \frac{1}{n_t}\left(q_{lr} + (n_t - 1)\cdot q_{lu}\right) \quad (11)$$

, where

q_{1r} =input energy used for root- pass

q_{1u} = input energy used for filling- pass

n_t =total passes number

Graphical processing of the obtained results are presented in figures 3…5.

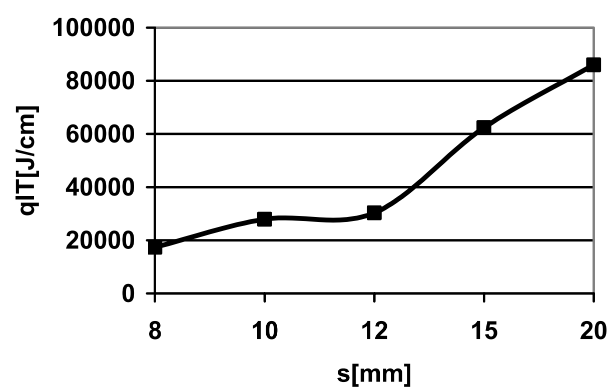

Fig.3 Total input energy variation at welding, according to sheet metal thickness

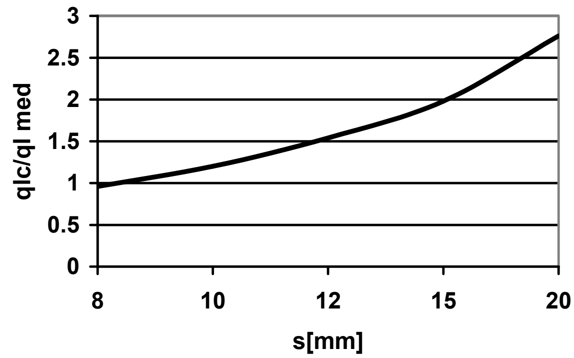

Fig.4 The variation of the proportion between the input active energy (of calculus) and the input line energy for a single pass, with the thickness of the sheet metal in a maximal passes variant

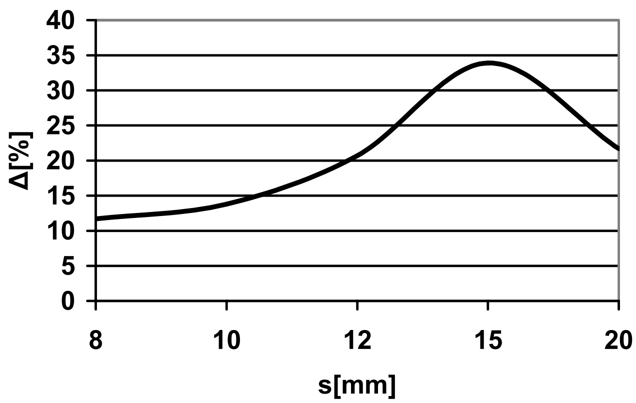

Fig.5 Quantitative influence (in percents) of relieving between the passes in the case of the maximum welding (technologically accepted) passes related to the reduction of calculus input energy (active), according to the sheet metal thickness

After analyzing these graphs, we can make the following observations:
-total input energy in case of multi-pass welding augments almost linearly with the sheet metal thickness;
-the rapport between the input calculus energy and the input medium energy used for obtaining a welding layer increases approximately linear with the sheet metal thickness.
-we can count on a reduction of the active input energy at welding with a maximal pass reported to a normal welding pass with 12…34% for a thickness of the sheet metal of 8…20mm; the maximal reduction was determined for 15mm thickness.

So, in the best case, by the united effect of the welding with a high number of passes and the pre-heating effect we can count on a reduction of 27..49% of the calculus input energy, thus bringing a reduction of the stresses and the majority of the residual strains in welding.

The term ” majority of the residual strains in welding” has been used because it has been experimentally proved the fact that the residual strain of angular trim increases in the same time with the increase of the welding pass number.

4. THE POSSIBILITY OF USING THE "WHITE METHOD" IN CALCULATING THE STRESSES AND STRAINS AT MULTI-LAYER WELDING

The case study presented at point 1 (for the thickness of 15mm of the sheet metal) shows (table 1) the fact that using the White method, the plasticized area (A_{pl}) and residual strains (σ_{rn}) have sensibly inferior values in comparison with the one calculated with the Okerblom method.

The Okerblom method, which has for the first time been used in the 60's, proved to be an approximately "covering" calculus method.

Therefore, a natural temptation to bring the results closer to the reality appears, and the most recently discovered White method, seams to be more convenient.

But after analyzing the (5), (6) and (7) formula - relations that are at the base of this method, we can observe that they do not use the concept of input calculus energy. Therefore, the application of the method has the same results no matter how many passes are used for the welding.

The method can't be extended for the calculus of the residual strains.

In this situation, the simplest thing to do is to use a correction coefficient (R).

Starting from the needed equality between the negative residual strains ratio and the calculus energies corresponding to the two methods:

$$\frac{\sigma_{rn}(Ok)}{\sigma_{rn}(W)} = \frac{q_{lc}(Ok)}{q_{lc}(W)} \quad (12)$$

, it results

$$q_{lc}(W) = \frac{\sigma_{rn}(W)}{\sigma_{rn}(Ok)} \cdot q_{lc}(Ok) = R \cdot q_{lc}(Ok) \quad (13)$$

, where obviously

$$R = \frac{\sigma_{rn}(W)}{\sigma_{rn}(Ok)}. \quad (14)$$

It is rationally for this definition of the correction factor R for the welding situation to be accepted in a usual number of passes (according to the 2nd and 3rd tables).

For the sheet metal of 10, 15 and 20mm thickness, already using the available data, the coefficients R and R' can be obtained, values presented in table 6 and the graph of variation in figure number 6.

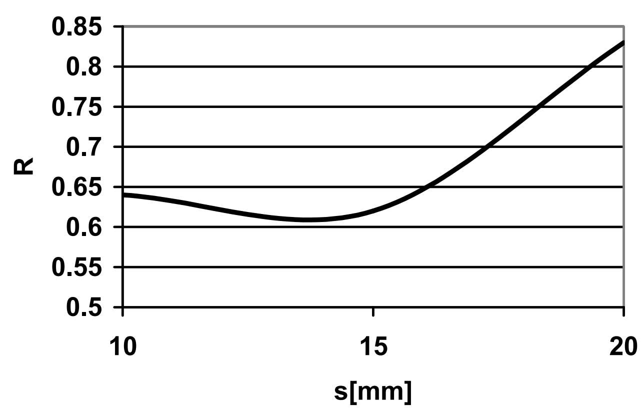

Fig.6 Variation of R coefficient with the metal sheet thickness

Table 6. Supplementary elements of calculus and the values of R correction coefficient

s[mm]	10	15	20
A[cm^2] (b=300)	30	45	60
Usual number of passes (n_t) (tab.2 şi 3)			
q_{lc}(Ok)[J/cm]	6469	13343	15932
σ_{rn}(Ok)[daN/cm^2]	-385	-529	-474
σ_{rn}(W)[daN/cm^2]	-245	-326	-393
R	0,64	0,62	0,83

A non-linear variation of R coefficient is noticed.

Therefore, for its use, it is necessary to use initially the both methods and establish the residual stresses of contraction with each of the methods

Calculus example

For welding two metal sheets in the conditions that have been mentioned earlier in the case study, for example, the determination of the reaction stresses that are developed in transversal reaction blocking is desired using the White method.

For a weld with a usual number of passes, it is obtained:

-transversal contraction

$$\Delta b = \frac{\mu}{0{,}335} \cdot \frac{R \cdot q_l}{s} = -\frac{0{,}85 \cdot 10^{-6}}{0{,}335} \cdot \frac{0{,}62 \cdot 13343}{1{,}5} = -0{,}014 cm;$$

-reaction stress

$$\sigma_{\Delta b} = \frac{\Delta b}{b} \cdot E = \frac{0{,}014}{30} \cdot 2{,}1 \cdot 10^6 = 980 daN / cm^2.$$

For welding with a maximal recommended number of passes, it results:

-transversal contraction

$$\Delta b' = \frac{\mu}{0{,}335} \cdot \frac{R \cdot q'_{lc}}{s} = -\frac{0{,}85 \cdot 10^{-6}}{0{,}335} \cdot \frac{0{,}62 \cdot 8821}{1{,}5} = -0{,}009 cm;$$

-reaction tension

$$\sigma'_{\Delta b} = \frac{\Delta b'}{b} \cdot E = \frac{0{,}009}{30} \cdot 2{,}1 \cdot 10^6 = 630 daN / cm^2.$$

If the Okerblom method were used, it would result, at welding with a usual number of passes, an almost unacceptable level of reaction stress of approximately 1580 daN/cm^2.

5. CONCLUSIONS

1° In the multi- layer welding case, the input energy that activates the forming of the stresses and the residual strains is significantly inferior to the amount of input energies used for every pass.

2° If the welding pass number is higher, the relieving stress phenomenon between passes accentuates, resulting a decrease of stresses and of the majority of the residual strains.

3° The establishment of the maximal pass number must, from a strict technical point of view, respect a series of technological restrictions. It is rationally acceptable that they will be dictated to the limit by the technological parameters that will ensure the correct achievement of the root layer and the exterior layer.

4° The analytical estimation of the stresses and the residual strains in the case of welding is better to be made in the projection stage of welding technologies. Besides avoiding a series of later unpleasant situations, thus one can be very confident that the chosen number of passes is the convenient one from a technical-economical point of view.

5° The general calculus method of the stresses and residual strains at welding, shown to us and built by Okerblom, brings results that we consider that are covering. The more modern method of White admits the evaluation of the residual stresses with a significantly lower calculus reserve. We can use it in the calculus of the stress relieving deformation by establishing equivalent calculus input energy.

6° In the case of butt-welded metal sheet of 8…20mm thickness, and with the preparation of the V-type commissural, the number of passes can be increased more or less compared to the usual technical recommendations. It has been estimated that this way the stresses and also the residual strains at welding can be reduced by almost 12…34%.

7° If high-preheating (250°C) is used also, the stresses and the strains can be reduced by approximately 27…49% according to the thickness of the metal sheet.

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