Contributions regarding chemical composition variation in ultrasonic field overlaying welding

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Abstract. Paper presents a new reconditioning method based on ultrasonic field and analyses the modified structure composition in three zones: filler material, thermal influenced zone, and base material. Also, chemical composition variation as a result of ultrasonic wave influence is studied besides the ultrasonic wave influence on dilution process.

1. Introduction
Overlaying welding consists in one layer or multiple metal layers deposition on a piece surface in order to increase corrosion resistance and wear. Between deposited layers a crystalline network compact continuity has to be realized by melting and pressure in special conditions. Geometrical elements of deposited zone by welding are presented in figure 1.

Figure 1. Geometrical elements of the metal plating deposited zone
P – piece; DL – deposited layer by welding; FM – filler material; BM – base material; TIZ – thermal influenced zone; p – penetration; h – thickness of the deposited layer; l – deposited layer width; s – deposited layer overhigh

Filler material layer FM and base material BM are not quite differentiate because a dilution of base material-filler material couple and has a very important role in functional and technological properties of the resulted joint. Dilution has to be as lower as it possible because deposited layer DL has to be as near is possible to filler material to get structure and specific properties for which filler material was chosen. Thermal influenced zone dimensions [10] and dilution here are very important also so, presented article will analyse this phenomenon in the section filler material-thermal influenced zone-base material. Overlaying welding presents some disadvantages like:
-chemical composition filler material-base material high compatibility;

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-non-uniformity and inhomogeneity of deposed layers that means non-uniform on section properties;
-many non-conformities appearance especially in the thermal influenced zone;
-need of thermal treatment;
-accenuation of dilution phenomenon that decrease functional properties in the developed metal couple;
-low productivity;

To eliminate these disadvantages or to diminish negative effects, paper presents a new plating method named overlaying welding in ultrasonic field.

Ultrasonic plating process efficiency depends first by way of ultrasonic wave is introduced in welding bath [9]. The process presents the following advantages:

- an important increased metal transfer rate from filler material;
- increased dynamic stability of the electric arc;
- increased air ionization around electric arc;
- finely crystalline structure because of alternative and symmetrical periodical action of ultrasonic wave;
- increased cooling speed and degree of subcooling at crystallisation beginning because of ultrasonic cavitation process
- decrease of dilution process;
- because layer of bead presents no internal stress, no heat treating is need;
- higher productivity;
- homogenous and uniform layers of bead;
- constant technological and functional properties on section.

From our research, we conclude that ultrasonic wave propagation has a great importance in metal transfer process along electric arc and in graining process because of ultrasonic cavitation process and accelerated scattering process.

2. Experimental results

Paper presents experimental results from overlaying welding in the case of filler material ultrasonic activation.

As a result of thermal cycle that acts on filler material and base material (heating-melting-cooling-solidification), different modification of chemical composition takes place because of dilution process. In the same time, technological and functional properties modifications occurs because of structure modifications in the three separate zones around demarcation line (filler material-thermal influenced zone-base material). For chemical composition variation on section, authors take all measurements from exterior surface of the deposed layer to base material interior with a 1 mm step.

Table 1. Chemical elements concentration variation at overlaying welding without ultrasonic activation on filler material-thermal influenced zone-base material based on X rays fluorescence (SR EN 24935/96)

| No. | Sample    | C   | Mn | Si  | S   | P   | Cr  | Ni  | Mo  | Nb  | Al  | Ti  | Cu   | Fe   |
|-----|-----------|-----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| 1   | Layer 5 mm| 0.015 | 0.025 | 0.07 | 0.001 | 0.005 | 21  | 63.8 | 8.5 | 3.35 | 0.38 | 0.25 | 0.001 | 3.5  |
| 2   | Layer 4 mm| 0.018 | 0.03  | 0.075 | 0.001 | 0.005 | 14  | 57.5 | 7.6 | 3.12 | 0.38 | 0.24 | 0.001 | 4    |
| 3   | Layer 3 mm| 0.019 | 0.036 | 0.09 | 0.001 | 0.005 | 16.4 | 53.2 | 6.7 | 2.43 | 0.37 | 0.24 | 0.001 | 4.3  |
| 4   | Layer 2 mm| 0.02  | 0.86  | 0.012 | 0.001 | 0.005 | 16  | 47.5 | 4.95 | 1.68 | 0.23 | 0.20 | 0.002 | 4.9  |
| 5   | Layer 1.5 mm | 0.025 | 0.1  | 0.13 | 0.001 | 0.006 | 15.2 | 38.2 | 3.82 | 1.24 | 0.17 | 0.15 | 0.003 | 5.3  |
| 6   | Layer 1 mm | 0.033 | 0.15 | 0.15 | 0.0011 | 0.006 | 25.4 | 27.4 | 2.41 | 0.95 | 0.12 | 0.02 | 0.003 | 6.4  |
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Separation zone between base material and filler material is marked by "Zero point". The samples were taken from different parts get by overlaying welding in ultrasonic field. X rays fluorescence was used for the chemical analysis according to ISO9556/2002. Table 1 and 2 presents the experimental results. Metal overlaying was done by using Inconel 625 Fe as filler material and AISi as base material.

Table 2. Chemical elements concentration variation at overlaying welding without ultrasonic activation on filler material-thermal influenced zone-base material based on X rays fluorescence (SR EN 24935/96)

| No. | Sample   | C    | Mn    | Si    | S    | P    | Cr   | Ni   | Mo   | Nb   | Al   | Ti   | Cu   | Fe   |
|-----|----------|------|-------|-------|------|------|------|------|------|------|------|------|------|------|
| 1   | Layer 5 mm | 0.015 | 0.027 | 0.06  | 0.001 | 0.005 | 20.85 | 62.8 | 7.4  | 3.35 | 0.37 | 0.24 | 0.009 | 1    |
| 2   | Layer 4 mm | 0.012 | 0.03  | 0.070 | 0.001 | 0.005 | 16.8  | 47.2 | 4.35 | 3.05 | 0.30 | 0.21 | 0.01  | 1.5  |
| 3   | Layer 3 mm | 0.015 | 0.085 | 0.08  | 0.001 | 0.005 | 16.4  | 42.8 | 4.05 | 2.5  | 0.25 | 0.37 | 0.20  | 0.01  | 2.1  |
| 4   | Layer 2 mm | 0.026 | 0.1   | 0.09  | 0.001 | 0.005 | 11.1  | 27.5 | 3.1  | 0.14 | 0.23 | 0.18 | 0.02  | 2.4  |
| 5   | Layer 1.5 mm | 0.034 | 0.18  | 0.10  | 0.001 | 0.006 | 16.8  | 24.1 | 2.46 | 0.12 | 0.17 | 0.16 | 0.03  | 2.8  |
| 6   | Layer 1 mm | 0.045 | 0.22  | 0.11  | 0.0013| 0.006 | 10.4  | 20   | 1.86 | 0.06 | 0.12 | 0.14 | 0.04  | 3    |
| 7   | Layer 0.5 mm | 0.048 | 0.25  | 0.12  | 0.0014| 0.007 | 16.2  | 14.8 | 1.5  | 0.05 | 0.089| 0.12 | 0.04  | 3.2  |
| 8   | Layer 0 mm  | 0.055 | 0.30  | 0.16  | 0.0015| 0.008 | 10    | 10.2 | 1.4  | 0.03 | 0.045| 0.1  | 0.05  | 14.5 |
| 9   | Layer -0.5 mm | 0.06  | 0.32  | 0.18  | 0.016 | 0.009 | 8     | 8.1  | 1.38 | 0.12 | 0.02 | 0.09 | 0.05  | 86   |
| 10  | Layer -1.5 mm | 0.08  | 0.45  | 0.19  | 0.0017| 0.01  | 5.9   | 7.5  | 1.35 | 0.014| 0.018| 0.007| 0.07  | 90.1 |
| 11  | Layer -1.5 mm | 0.10  | 0.5   | 0.23  | 0.002 | 0.01  | 4     | 5.4  | 1.34 | 0.015| 0.017| 0.005| 0.18  | 95   |
| 12  | Layer -2 mm  | 0.12  | 0.53  | 0.24  | 0.002 | 0.04  | 3.8   | 1.4  | 1.38 | 0.016| 0.017| 0.004| 0.07  | 97.1 |

Figure 3 presents Fe concentration variation, measured from deposed layer exterior (Inconel 625Fe) to base material (AISi 4130).

The result is a non-uniforme variation of Fe concentration in the section, that increases slowly in the filler material and than a abrupt increasing in the thermal influence zone. A normal increasing is seen in the base material because of inhibited dilution phenomenon. In all zones, Fe concentration
increasing is attenuated in the case of overlaying welding in ultrasonic field, from filler material to base material.

![Figure 2](image.png)

**Figure 2.** Variation of Fe concentration measured from exterior of deposed layer to base material
- a - at overlaying welding without ultrasonic field activation;
- b - at overlaying welding with ultrasonic field activation of electrode wire;

C concentration variation, measured from deposed layer exterior to base material in the three distincte zone (BM-TIZ-FM) is presented in the figure 3.

![Figure 3](image.png)

**Figure 3.** Variation of C concentration measured from exterior of deposed layer to base material
- a - at overlaying welding without ultrasonic field activation;
- b - at overlaying welding with ultrasonic field activation of electrode wire;

A slow increasing of C content is observed in the filler material because of diffusion process from base material to filler material. Also, a sharp increasing of C, in the thermal influenced zone and base material in the case of overlaying welding without ultrasonic activation is observed. In the case of ultrasonic activation of the filler material, C content increasing in the thermal influenced zone is much blurred because of dilution phenomenon and diffusion phenomenon inhibition from base material to filler material.
Variation of Cr concentration in depth, measured from exterior of deposed layer to base material in the three separate zone (FM-TIZ-BM) is presented in the figure 4.

Figure 4. Variation of Cr concentration measured from exterior of deposed layer to base material
   a - at overlaying welding without ultrasonic field activation;
   b - at overlaying welding with ultrasonic field activation of electrode wire;

A sharp decreasing of Cr concentration is observed in the filler material and thermal influenced zone and a slow decreasing in the base material in the case of overlaying welding without filler material ultrasonic activation. In the case of overlaying welding with filler material ultrasonic activation, Cr concentration decreasing is slower, being low in the thermal influenced zone, that means low brittle carbon because of dilution phenomenon inhibition and reducing of the diffusion phenomenon from filler material to base material.

Variation of Ni concentration, in the three distincte zone (FM-TIZ-BM) is presented in figure 5. Very close variation with Cr behavior is clear with the observation of a more accentuated decrease in the three studied zone.

Figure 5. Variation of Ni concentration measured from exterior of deposed layer to base material
   a - at overlaying welding without ultrasonic field activation;
   b - at overlaying welding with ultrasonic field activation of electrode wire;
Variation of Si concentration, in the same conditions is presented in fig. 6. A slower Si content increasing is observed in the filler material because of diffusion from base material to filler material and because of dilution, a sharp increasing in the thermal influenced zone and a slow increasing in the base material at overlaying welding without ultrasonic activation. In the situation of ultrasonic activation, Si content increasing is slower because of diffusion phenomenon inhibition from base material to filler material and dilution phenomenon reducing.

![Figure 6. Variation of Si concentration measured from exterior of deposed layer to base material
a - at overlaying welding without ultrasonic field activation;
b - at overlaying welding with ultrasonic field activation of electrode wire;](image)

Mo concentration variation is presented in the figure 7. A sharp decreasing of Mo content is observed in filler material and thermal influenced zone and a slow decreasing in base material in the situation of no ultrasonic activation. In the case of ultrasonic activation of the filler material, Mo content decreasing is much lower because of dilution phenomenon inhibition and diffusion phenomenon decreasing under ultrasonic action.

![Figure 7. Variation of Mo concentration measured from exterior of deposed layer to base material
a - at overlaying welding without ultrasonic field activation;
b - at overlaying welding with ultrasonic field activation of electrode wire;](image)
Experimental results showed that dilution is the phenomenon that conduces to concentration variation on section, and diffusion process is developed between used materials involved in the process. Dilution is the principal process that is developed on overlaying welding method which influence all the technological and functional properties of the resulted material couple. Experiments disclosed that by the time dilution increase, technological and functional properties of the deposed layer decreases. Considering this, in order to control and to conduct the dilution phenomenon, a thorough analysis is needed for each influence factor of the overlaying welding. Considering experimental results of overlaying welding method in ultrasonic field, the paper presents the following elements:

- current intensity - increasing this parameter, penetration increases, so dilution increase;
- electric arc tension at welding - increasing this parameter means width bead increasing penetration decrease so dilution decrease;
- welding speed - welding speed increase, penetration decreases, dilution decreases;
- welding linear energy - when increasing, penetration increases, dilution the same;
- protective gas type - has a different influence as a function of using way: 100% Ar - needs low voltage, that means low penetration and lower dilution; 100% He needs higher welding speed, that means lower penetration and lower dilution; mix of Ar+He conduct to a higher penetration, respective higher dilution.
- base material type - has a different influence of dilution as a function of component elements nature, compatibility to base material and cristalisation structure;
- filler material type - has a different influence according to nature of element component elements, base material compatibility and cristalization structure;
- penetration - higher dilution according to penetration;
- number of deposed layers - according to increased layers, dilution increases;
- initial surface roughness - indicates demarcation line between deposed layer and base material and influence the mechanical anchorage that depends on dilution;
- ultrasonic intensity - as ultrasonic intensity increases, diffusion process increases and dilution also;
- ultrasonic frequency - as frequency increases, subcooling speed increases, diffusion decreases and dilution also and solidification is intensified;
- ultrasonic activation time - increase activation time, solidification process is intensified, increase structure crumbling;
- ultrasonic wave type - longitudinal, torsional, surface waves, radial waves, has a different influence on dilution, lowest being in the case of longitudinal waves and highest in the case of surface waves.

3. Conclusion

Regarding experimental results, the following conclusions are available:
- a quality overlaying welding process optimization in ultrasonic field is done by dilution as objective function, dilution that has an important influence on technological and functional properties of the resulted couple;
- analyzing changes in concentrations of chemical elements, measured from deposed layer to base material on FM-TiZ-BM (2.0...5.0)mm, the following results were found: C and Si increase content, an important Fe concentration increasing, Cr, Mo and Ni decrease content because diffusion process inhibition from filler material to base material and dilution processes reducing.
- dilution, as a very complex function depends on: current intensity at welding, electric arc tension, welding speed, liniar welding energy, protective gas type, base material type, penetration, number of deposed layers, initial base material roughness, ultrasonic intensity, ultrasonic frequency, ultrasonic oscillation amplitude, ultrasonic activation type, ultrasonic oscillation type;

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