The influence of the surface preparation of aluminium alloys for brazing upon the hardness of the assembly

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Abstract. The wider use of aluminum and its alloys also involves specific technologies for reconditioning and repairing the various components. Specialist studies have shown that a more advantageous technique, from an economical point of view, than welding with less polluting and good mechanical properties is brazing. The only disadvantage of this process is the stage of preparing the surfaces to be assembled. Specialty literature and many published papers provide detailed information with direct reference to the mechanical and physical properties of aluminum alloy assemblies refurbished by brazing depending on the surface preparation mode. The present paper aims to make a study, based on experimental data, on how the surface preparation influences the hardness of aluminum alloy assemblies refurbished by brazing. The areas of the base materials, the filler material as well as the thermal diffusion zones resulting from the brazing operation will be studied. The main problem is the difference in hardness between the materials to be assembled and the material with which they are assembled. This can be a major cause, which can generate defects in operating cycles by lowering the strength of the assembly. By choosing an optimal surface preparation technology, we can reduce these differences by obtaining an assembly with uniform properties in all its structure, so with a longer service life.

1. Introduction

In all industrial fields, aluminum and its alloys are increasingly spreading due to their characteristics. The paper aims to develop a non-demountable assembly method, using a 6061 aluminum alloy with great use in all industrial branches, [1].

A property that is bound to be taken into account is the hardness of the combined components and the influence of the brazing temperature on the modification.

Hardness is the mechanical property of materials which consists in their ability to resist the external penetration of a foreign body.

Hardness is the mechanical property of the greatest importance because in most cases the operation in the parameters resulting from the specification of a part and its life depend on this property, [2].

A method of verifying in fabrication the metallurgical properties of the base and filler materials can also be considered as measuring the micro-hardness of the brazed joints. These tests are frequently used for research and design activity to study the diffusion characteristics of the filler material, [3].

Of particular importance is the modification of the hardness of the base material after heating to the brazing temperature.
2. Materials used
In order to establish the intrinsic quality of the processes and the parameter reference values, it is necessary to perform a series of specimens on the same type of base material, with the same type of filler material and observing the variations of the parameters, [4].

Thus, for each technology we performed 4 samples, as can be seen in figure 1.

![Experimental specimens](image)

**Figure 1.** Experimental specimens.

Brazing of the experimental specimens was performed in the furnace due to the homogeneity of the heating temperature and its exact control.

Thus, the brazing operation was carried out in an electric furnace with radiant resistance at 843K and was cooled in the atmosphere, [5].

The furnace maintenance time and the surface preparation procedure were varied as shown in table 1.

| No. | Preparation procedure | Furnace maintenance time | Symbol | Overlay area [mm²] |
|-----|-----------------------|--------------------------|--------|--------------------|
| 1   | TP I AL               | X                        | T1     | 30x10.3=309        |
| 2   | TP I AL               | X                        | T2     | 30x6.8=204         |
| 3   | TP I AL               | X                        | T3     | 30x7.6=228         |
| 4   | TP I AL               | X                        | T4     | 30x7.5=225         |
| 5   | TP II AL              | X                        | A1     | 30x7.4=222         |
| 6   | TP II AL              | X                        | A2     | 30x6.9=207         |
| 7   | TP II AL              | X                        | A3     | 30x7.1=213         |
| 8   | TP II AL              | X                        | A4     | 30x7.4=222         |
| 9   | TP III AL             | X                        | V1     | 30x7.4=222         |
| 10  | TP III AL             | X                        | V2     | 30x7.2=216         |
| 11  | TP III AL             | X                        | V3     | 30x8.1=243         |
| 12  | TP III AL             | X                        | V4     | 30x7.9=237         |
| 13  | TP IV AL              | X                        | M1     | 30x6.3=189         |
| 14  | TP IV AL              | X                        | M2     | 30x7.8=234         |
| 15  | TP IV AL              | X                        | M3     | 30x7.2=216         |
| 16  | TP IV AL              | X                        | M4     | 30x8.6=258         |

The overlay area is calculated by multiplying the width of the 30 mm standard specimen with the X mm overlap width.

The four surface preparation technologies of aluminum alloy experimental test pieces are:
TP I AL – without surface preparation;
TP II AL – acetone degreasing of the entire surface of standard specimens;
TP III AL – pickling in Almeco 100;
- Acetone degreasing of surfaces;
- Chemical alkaline degreasing (soda) 30min;
- Washing in hot water bath;
- Washing in cold water bath;
- Pickling in ALOCLENE 100 12min;
- Washing in hot water bath;
- Washing in cold water bath;
- Rinse in nitric acid 5min;
- Washing in hot water bath;
- Washing in cold water bath;
- Hot air jet drying.

TP IV AL – Pickling in DEOXIDIZER 6/16
- Acetone degreasing of surfaces;
- Pickling in DEOXIDIZER 30min;
- Washing in hot water bath;
- Washing in cold water bath;
- Rinse in nitric acid;
- Washing in hot water bath;
- Washing in cold water bath;

The experimental samples were subjected to the Vickers method of hardness tests using the Shimadzu HMV 2TE Hardness Meter, SN 163034501188, Japan.

Five series of 5 measurements were performed on each specimen according to the scheme shown in figure 2:

![Figure 2](image)

**Figure 2.** The Vickers microstructure measurement scheme for experimental samples.

Measurements are distributed as follows:
1: in the base material 1;
2: in the diffusion zone of the base material 1 with the additive material;
3: in the filler material;
4: the diffusion zone of the filler material with the base material 2;
5: in the base material 2.

Measurements were made under the following conditions:
- force of thrust: 50gr ≈ 0.4903N;
- force maintenance time 15seconds;
- magnifying glass used: 40X;
- the distance between fingerprints: 0.25mm.

### 3. Experimental results

For the base material not subjected to the thermal influence due to brazing, the hardness values measured by the Vickers method are shown in the table 2:
The average hardness of the base material is 68.274HV. By eliminating the maximum and minimum values in the measurement string (6 values), we obtain an average value of the hardness of the base material not influenced by the brazing temperature of 61.735HV. We can see with great interest that the error in the elimination of the maximum and minimum values in the case of considering the 30 values of the hardness is 11.059%. Therefore, it is necessary to use a more complex model of hardness determination using statistical methods.

In view of the above, table 3 shows the hardness values resulting from the arithmetic mean calculation for a minimum of 3 input data for each displayed value. Because the table generated by the EXCEL program is large, I will present a picture of it.

### Table 2. Hardness values for brazing base material.

| Sample | I | II |
|--------|---|----|
|        | 1 | 2  | 3  | 4  | 5  | 1  | 2  | 3  | 4  | 5  |
| T1     | 39.29 | 43.06 | 55.83 | 46.2 | 44.12 | 38.93 | 52.83 | 55.31 | 48.13 | 40.66 |
| T2     | 43.79 | 48.99 | 57.39 | 47.83 | 43.4 | 39.72 | 48.66 | 54.84 | 47.38 | 39.82 |
| A1     | 43.27 | 51.14 | 58.73 | 50.38 | 48.32 | 45.15 | 50.89 | 56.31 | 52.27 | 45.15 |
| A2     | 40.28 | 52.67 | 56.48 | 51.4 | 42.47 | 44.26 | 53.32 | 58.31 | 52.68 | 47.26 |
| V1     | 41.79 | 53.05 | 64.54 | 52.69 | 41.9 | 42.19 | 56.18 | 44.85 | 54.97 | 43.57 |
| V5     | 43.41 | 52.41 | 48.77 | 53.73 | 43.62 | 40.17 | 52.67 | 65.94 | 54.18 | 45.18 |
| M1     | 41.83 | 54.18 | 54.49 | 53.61 | 43.5 | 39.97 | 52.89 | 57.63 | 54.38 | 42.73 |
| M5     | 42.67 | 53.95 | 55.61 | 54.78 | 44.85 | 38.53 | 55.07 | 53.95 | 53.49 | 42.47 |
| Arithmetic average | 42.04125 | 51.175 | 56.48 | 51.3275 | 43.9888 | 41.115 | 52.8138 | 55.8925 | 52.185 | 43.355 |

### Table 3. The hardness values provided by the Excel program in experimental specimens.

| Sample | I | II |
|--------|---|----|
|        | 1 | 2  | 3  | 4  | 5  | 1  | 2  | 3  | 4  | 5  |
| T1     | 46.47 | 47.9 | 55.21 | 52.6 | 43.88 | 45 | 49.18 | 54.6 | 46.21 | 44.98 |
| T2     | 42.69 | 50.23 | 56.27 | 51.14 | 43.2 | 45.2 | 48.27 | 55.15 | 49.37 | 51.35 |
| A1     | 43.78 | 51.38 | 48.92 | 51.62 | 44.69 | 42.18 | 50.36 | 52.73 | 50.95 | 46.28 |
| A2     | 41.88 | 52.84 | 64.17 | 53.16 | 43.58 | 44.43 | 52.79 | 53.72 | 53.36 | 43.86 |
| V1     | 39.45 | 54.51 | 51.38 | 55.19 | 46.92 | 39.86 | 56.38 | 55.25 | 56.01 | 44.05 |
| V5     | 44.15 | 57.18 | 56.26 | 55.21 | 43.83 | 38.27 | 52.66 | 51.17 | 53.51 | 42.75 |
| M1     | 41.18 | 56.11 | 60.37 | 54.92 | 41.29 | 39.71 | 54.87 | 52.38 | 53.88 | 42.27 |
| M5     | 43.12 | 55.46 | 57.21 | 56.42 | 42.79 | 41.33 | 55.48 | 56.17 | 53.77 | 43.83 |
| Arithmetic average | 42.84 | 53.2013 | 56.22 | 53.7825 | 43.7725 | 41.9975 | 52.4988 | 53.8963 | 52.1325 | 44.9213 |

| Sample | V |
|--------|---|
|        | 1 | 2  | 3  | 4  | 5  |
| T1     | 41.7 | 49.17 | 57.01 | 43.83 | 43.36 |
| T2     | 39.92 | 44.68 | 56.25 | 47.27 | 48.32 |
| A1     | 42.18 | 51.56 | 62.41 | 52.26 | 44.31 |
| A2     | 41.67 | 42.11 | 47.3 | 52.82 | 43.19 |
| V1     | 39.35 | 53.48 | 54.84 | 54.27 | 42.48 |
| V5     | 40.22 | 51.12 | 50.31 | 52.87 | 40.19 |
| M1     | 42.26 | 54.12 | 55.19 | 56.21 | 44.29 |
| M5     | 41.81 | 53.87 | 57.38 | 56.11 | 45.39 |
| Arithmetic average | 41.1388 | 51.2638 | 55.0863 | 51.955 | 43.9413 |
Approximately 600 measured values resulted in 200 series of Vickers micro-hardness. Because the table generated by the EXCEL program is large, I will present a picture of it. A series of calculations are presented below in table 4:
- the arithmetic mean of the values \( \frac{1}{5} \) for \( T_1, T_3, A_1, A_3, V_1, V_3, M_1 \) and \( M_3 \) test pieces for the five series of measurements (example; \( \text{SUM}((C3+H3+M3+R3+W3)/5=42.278) \) etc.);
- the arithmetic mean of the results previously obtained vertically.

**Table 4.** Calculation of average hardness provided by Excel for experimental specimens.

| Crt | Sample symbol | Horizontal arithmetic average |
|-----|---------------|------------------------------|
| 1   | \( T_1 \)     | 42.278 48.428 55.592 47.394 43.4 |
| 2   | \( T_3 \)     | 42.264 48.166 55.98 48.598 45.218 |
| 3   | \( A_1 \)     | 43.312 51.066 55.82 51.496 45.75 |
| 4   | \( A_3 \)     | 42.504 52.746 55.996 52.684 44.072 |
| 5   | \( V_1 \)     | 40.528 54.72 54.172 54.626 43.784 |
| 6   | \( V_3 \)     | 41.244 53.208 54.49 53.9 43.114 |
| 7   | \( M_1 \)     | 40.99 54.434 56.012 54.6 42.816 |
| 8   | \( M_3 \)     | 41.492 54.756 56.064 54.914 43.812 |
|     | Arithmetic average | 41.8265 52.1905 55.5158 52.2765 43.9958 |

Table 5 shows the hardness values for samples \( T_1 \) and \( T_3 \).

**Table 5.** The hardness values of \( T_1 \) and \( T_3 \).

| \( T_1 \) | 39.29 38.93 46.47 45 41.7 |
|-----------|-----------------|
|           | 43.06 52.83 47.9 49.18 49.17 |
|           | 55.83 55.31 55.21 54.6 57.01 |
|           | 46.2 48.13 52.6 46.21 43.83 |
|           | 44.12 40.66 43.88 44.98 43.36 |
| \( T_3 \) | 43.79 39.72 42.69 45.2 39.92 |
|           | 48.99 48.66 50.23 48.27 44.68 |
|           | 57.39 54.84 56.27 55.15 56.25 |
|           | 47.83 47.38 51.14 49.37 47.27 |
|           | 43.4 39.82 43.2 51.35 48.32 |

Figure 3 and figure 4 show the hardness distribution for the \( T_1 \) and \( T_3 \) samples.

**Figure 3.** Hardness graph specimen \( T_1 \).

**Figure 4.** Hardness graph specimen \( T_3 \).
In the first set of specimens there are areas where the filler material has not adhered to the base material due to the non-preparation of the surfaces prior to the brazing operation. The diffusion zones between the base and the filler are not well contoured, and the hardness is closer to the hardness of the base material. At the same time, the lack of areas where we should have high filler material makes the entire brazed assembly considered inadequate in terms of hardness.

Table 6 gives the hardness values for samples A1 and A3.

|     | A1     | A2     | A3     | A4     | A5     |
|-----|--------|--------|--------|--------|--------|
| 1   | 43.27  | 45.15  | 43.78  | 42.18  | 42.18  |
| 2   | 51.14  | 50.89  | 51.38  | 50.36  | 51.56  |
| 3   | 58.73  | 56.31  | 48.92  | 52.73  | 62.41  |
| 4   | 50.38  | 52.27  | 51.62  | 50.95  | 52.26  |
| 5   | 48.32  | 45.15  | 44.69  | 46.28  | 44.31  |

Figure 5 and figure 6 show the distribution of hardness in the five sections of the samples.

In the second set of specimens (A1 and A3) a relatively uniform distribution of hardness can be observed, delimiting the three zones: the base material areas, the diffusion zones between the base material and the filler material and the filler material area. It is to be noticed that the hardness increases from the outside to the interior, respectively from the base material to the filler material, this being obvious due to the superior hardness of the filler material, but also to the application of the temperature from the outside to the interior, thus reducing the base material hardness and increasing elongation. This phenomenon is mainly due to the inadequate preparation of surfaces prior to the brazing process, using TP II AL technology, namely acetone degreasing of the surfaces.

Table 7 shows the hardness values for samples V1 and V3.

|     | V1     | V2     | V3     |
|-----|--------|--------|--------|
| 1   | 41.79  | 42.19  | 39.45  |
| 2   | 53.05  | 56.18  | 44.85  |
| 3   | 64.54  | 51.38  | 64.54  |
| 4   | 52.69  | 54.97  | 52.69  |
| 5   | 41.9   | 43.57  | 41.9   |
|     | V3     | V4     | V5     |
|     | 43.41  | 40.17  | 38.27  |
|     | 52.41  | 52.67  | 52.41  |

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The figures 7 and 8 show the distribution of the hardness of the experimental samples V1 and V3.

When using the TP III AL preparation technology (Almeco 100 pickling), the diffusion zones between the base material and the filler material have greater widths and predominate hardnesses closer to the hardness of the filler material than the hardness of the base.

This set of specimens can be considered optimal in terms of brazing assembly hardness.

Table 8. Hardness values for specimen M1 and M3.

|       | M1 |             |       | M3 |             |
|-------|----|-------------|-------|----|-------------|
|       | 41.83 | 39.97 | 41.18 | 39.71 | 42.26 |
|       | 54.18 | 52.89 | 56.11 | 54.87 | 54.12 |
|       | 54.49 | 57.63 | 60.37 | 52.38 | 55.19 |
|       | 53.61 | 54.38 | 54.92 | 53.88 | 56.21 |
|       | 43.5  | 42.73 | 41.29 | 42.27 | 44.29 |

Table 8 shows the hardness values for samples M1 and M3.

The figures 9 and 10 show the distribution of the hardness of the experimental samples M1 and M3.
Although we have been using a relatively efficient surface preparation technology, TP IV AL technology (6/16 Deoxidizer pickling) has no satisfactory results, yet it has relatively large diffusion areas with low hardness.

4. Conclusions
The drying time of the furnace samples ((20 and 30) minutes) at the baking temperature (570°C) does not significantly affect the hardness of the base materials, the filler material, nor the hardness of the diffusion area between the base material and the filler material.

There is a slight change in hardness (between the values in column 1 and those in column 5) due to the direct influence of temperature on one part of the sample. Thus, we can easily determine the positioning of the sample in the furnace: the lower hardness base material is one that has been directly influenced by the temperature and the higher hardness base material has been in direct contact with the oven tray. The diffusion zones between the feed material and the base materials (columns 2 and 4) have similar hardness and the maximum hardness can be seen in the filler material (column 3).

In the case of the use of TP III AL surface preparation technology (Aloclene 100 pickling), the diffusion zones between the base material and the filler material have greater widths and predominate hardness closer to the hardness of the filler material than the hardness of the base material.

The technology of optimal training in terms of hardness is TP III AL.

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