Subsurface analysis of 6082-T6 Aluminium alloy's mechanical properties subjected to small particles erosion

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Abstract. 6082-T6 aluminium alloy is a ductile metal. When subjected to small particles erosion, sub-surface deformations are expected due to the particle impact. Plasticity is one of the properties which might reveal the rate of the deformations. As a result of plastic deformation, mechanical properties of the samples are expected to change with distance from the surface. Typically, the depth of the plastically deformed region could be between 5 and 200 µm. In order to understand the plasticity of the materials, nanoindentation researches were conducted. Aluminium alloy samples were previously subjected to hard material particles jets (Al2O3) under different values of incident angle, between 15 and 90 degrees. After a 3D scan of the resulted surfaces, the samples were cut in such a manner that the middle section remained visible and prepared for nanoindentation analysis. The paper presents the experiments conducted as well as some of the achieved results.

1. Introduction
Aluminium alloys are largely used in the automotive and aerospace industries, due to the combination between their low specific mass and mechanical properties. Having also good formability and machinability (such as rolling, extrusion, stamping, casting, etc) they are also suitable for industrial application.

2. Materials and methods
2.1. Material
Material subjected to tests was AA6082-T6 aluminium alloy laminated sheets, with a nominal thickness of 3mm. The dimensions of the samples provided by the Mechanical Department of the Kocaeli University were 50x50x3mm. According to (1), aluminium alloy 6082 is a medium strength alloy with excellent corrosion resistance, having the highest strength of the 6000 series alloys; it is known as a structural alloy. In plate form, 6082 is the alloy most commonly used for machining. The addition of a large amount of manganese controls the grain structure which in turn results in a stronger alloy. Table 1 shows the chemical composition of the AA6082-T6 aluminium alloy, while Table 2 offers some of its physical properties.
Table 1. Chemical composition of the AA6082-T6 aluminium alloy [1].
Spec: BS EN 573-3:2009

| Chemical Element   | % Present |
|--------------------|-----------|
| Manganese (Mn)     | 0.40 - 1.00 |
| Iron (Fe)          | 0.0 - 0.50  |
| Magnesium (Mg)     | 0.60 - 1.20 |
| Silicon (Si)       | 0.70 - 1.30 |
| Copper (Cu)        | 0.0 - 0.10  |
| Zinc (Zn)          | 0.0 - 0.20  |
| Titanium (Ti)      | 0.0 - 0.10  |
| Chromium (Cr)      | 0.0 - 0.25  |
| Other (Each)       | 0.0 - 0.05  |
| Others (Total)     | 0.0 - 0.15  |
| Aluminium (Al)     | Balance    |

Table 2. Physical properties of the AA6082-T6 aluminium alloy [1].

| Physical Property       | Value         |
|-------------------------|---------------|
| Density                 | 2.70 g/cm³    |
| Melting Point           | 555 °C        |
| Thermal Expansion       | 24 x10^-6 /K  |
| Modulus of Elasticity   | 70 GPa        |
| Thermal Conductivity    | 180 W/m.K     |
| Hardness Brinell        | ~95 HB        |

2.2. Method
Experiments which generated the specimens and also results and conclusions are described in [2] and [3]. For the tests presented in the current paper three types of specimens have been considered: specimen coded 06A which corresponds to 120 mesh erodent particles at 1.5 bar pressure at an impact angle of 90 degrees, specimen coded 07A, which corresponds to 120 mesh erodent particles at 3.0 bar pressure at an impact angle of 90 degrees and specimen coded 11A which corresponds to 120 mesh erodent particles at 1.5 bar pressure at an impact angle of 15 degrees.

A nanoindentation of the specimens’ subsurface along their middle line has been set, having the main aim the analysis of the Modulus of Elasticity and the Hardness of the materials in the layers right below the surface due to Al₂O₃ particles impact. To achieve the needed surface, the specimens had to be cut axially, along their middle line, so that after processing steps, the analysed surface should be as close as possible to the middle line.
Figure 1. Specimen cutting: b – cutting tool width, δ – withdrawn part. i – specimen 11A, ii – specimen 07A

Figure 2. Geometry of nanoindentation.

Figure 2 shows the geometry of nanoindentation. Starting as close as possible from the cavity surface, there are 10 indentation points towards the base of the specimen, with a pitch of 0.02mm. To avoid an extremely long process of measurements, the surface was split in three regions, as presented in figure 2. Left and right zones are placed near the start/end of the eroded surface, containing, each of them, 50 measurement points, structured in five columns, each of 10 rows. Distance between columns is 5mm. The middle zone consists of 100 to 200 measurement points (10 columns to 20 columns), organized similar to left and right zones, symmetrical to the maximum depth of the cavity.

The nanoindentation tip characteristics are presented in table 3 and test inputs in table 4.
| Name               | Value                             | Units   | Name               | Value   | Units   |
|--------------------|-----------------------------------|---------|--------------------|---------|---------|
| Tip Name           | TB22118 BASIC                     |         | Allowable Drift Rate | 0.050   | nm/s    |
| Area Coefficient 1 | 2.539610175e+001                  |         | Depth Limit        | 1000.000 | nm      |
| Area Coefficient 2 | 3.876214090e+002                  |         | Peak Hold Time     | 10.000  | s       |
|                    |                                   |         | Percent To Unload  | 90.000  | %       |
|                    |                                   |         | Perform Drift Test Segment | 1           |         |

3. Results and discussions
For measurements a Keysight Nano Indenter G200 has been used, the experiments being conducted in accordance with ISO 14577-1:2015.

Figure 3 shows a typical imprint after tests, and Table 5 shows results of the tests (mean values).

![Figure 3](image)

Figure 3. Geometry of the imprints during tests, for two adjacent columns.

Notation made in table 5 are as follows:
- 6A, 7A, 11A are the codes of the specimens
- LE 1-5 is used to address values for the left edge (named Left in figure 2), columns 1 to 5. As a general aspect regarding notation, column numbers increase from the center to the edges.
- LM 1-10 represents the measurements on the left side of the middle region.
- RM 1-10 represents the columns to the right of the middle region.
- RE 1-5 is used to address columns near the right edge of the cavity.
- Ref is a reference measurement made in the vicinity of the specimen’s center.

Analyzing values offered by tests, the following conclusions can be made:
- Material hardness shows small changes with the specimens, from 1.202 at 11A-LM to 1.512 for specimen 7A, left edge.
- Significant changes are noticed for the Modulus of Elasticity, both from one specimen to another, but also from one place to another at the same specimen. Also, for specimens 6A and 7A, subjected to particle jets perpendicular to their surfaces, a significant increase of the modulus has been noticed. This increase in value goes up to 88GPa related to 70GPa as stated by producers, which means an increase with 25% in properties. Specimen 11A shows almost no changes in Modulus of Elasticity values related to manufacturer specifications.
During tests it was noticed that Modulus of Elasticity is decreasing from the edge of the cavity to the interior of the specimen. Figure 4 shows the variation of the mean values for Modulus of Elasticity in respect to the distance from the cavity edge to the center of the specimen. Higher values are noticed near the edge.

Figure 4. Modulus of Elasticity and Hardness variation with the distance to the cavity edge.
As a final conclusion, it can be stated that important changes in material properties occur during impact with hard materials. In [2] and [3] experiments regarding the dependency between particle dimensions and particle speed to the shape of cavities have been conducted. Current research noticed that changings in material properties are also influenced by the way in which materials are exposed to wear particles. Further researches have to be oriented toward two aspects:

- Investigation of the way in which changes in material properties are related to the changes in shape of the material grains;
- Investigation related to the ratio between wear and plastic deformation of the material in the process of generating the cavity. If the cavity is generated mainly as an effect of grain deformation, thus increasing material properties, maybe a sandblasting similar procedure using Al₂O₃ after aging might be an advantage in obtaining materials with better properties.

References

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