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# Fracture Analysis of Vehicle-Mounted Telescoping Communications Mast

Nada Ilić [1)]
Ljubica Radović[1)]
Maja Mladenović[1)]
Jovana Mandić[1)]
Vesna Pejović[1)]

**In this paper a fractured connector plate for a telescoping antenna mast made of aluminum alloy EN-AW 2007 was examined. The goal of the investigation was to determine the cause of fracture which occurred during attempting to raise the antenna. Specimens taken from the mast were visually examined, and the fracture surface was examined using a scanning electron microscope. Chemical analysis, microstructural analysis, electrical conductivity measurements, tensile test and hardness test were performed in order to investigate the properties of the material. Fracture occurred fast and visual and fractographic examinations showed that there is no visible plastic deformation near the fracture surface, which are characteristics of a quasibrittle fracture. It was shown that the mechanical properties of the examined specimens do not satisfy the minimal values defined in the standard for this material. All conducted tests indicated that the material had not been heat treated and mechanically worked, so applied stress during handling/raising the antenna led to the rapid quasibrittle fracture.**

*Key words*: **alloy EN AW-2007, telescoping mast, fractography.**

## Itroduction

ONE of the most effective and inexpensive radio antenna is a mast antenna that is mounted on the vehicle. It must be lightweight with high mechanical strength, mobile and allow easy mountings.

In spite of requirement for high material quality and calculation of stresses and strengths, several reports on antennas failure, with different reasons, were published [1-4]. That means that the mast's strength must be greater than the stress caused by the loads applied to it. The telescoping vehicle-mounted communications mast located on the PEBZOTS system fractured after attempting to raise the antenna. Further conditions under which the fracture occurred are unknown. The aim of this paper is to determine the cause of fracture that occurred during handling/raising the antenna mast.

## Experimental

The fractured antenna mast is made of aluminum alloy. The chemical composition is given in Table 1. The used material, is alloy EN AW-2007 (AlCu4PbMgMn), according to SRPS EN 573-3 [5].

A photograph of the base of the mast is shown in Fig.1. The cylinder and connector plate were machined from one round bar with a diameter of at least 370 mm.

After visual observation by the naked eye and by using magnifying glass, the macroscopic appearance of the fractured part was photographed.

**Table 1.** Chemical composition of the antenna mast.

| Element | Mass. % |
|---|---|
| Cu | 4.51 |
| Mg | 0.65 |
| Mn | 0.60 |
| Si | 0.49 |
| Fe | 0.42 |
| Zn | 0.40 |
| Bi | 0.07 |
| Pb | 0.80 |
| Sn | 0.02 |
| Al | bal. |

Hardness was measured by Brinell method (HB 2,5/62,5), according to SRPS EN ISO 6506-1 [6].

Tensile tests were performed in accordance with SRPS EN ISO 6892-1 [7] on three tensile specimens taken in longitudinal direction from the cylindrical part of the mast, and three specimens taken from the connector plate of the mast, as shown in Fig.1. The $L_o$ length of the short proportional round tensile samples was 30 mm at a sample diameter of 6 mm. The tensile test was performed at the strain rate of $\dot{\varepsilon}$ =2.7·10$^{-3}$ s$^{-1}$.

The fracture surfaces of the tensile specimens were examined by scanning electron microscope JEOL 6010LV.

Electrical conductivity of the mast material was measured at 60kHz using Sigmatest D2.068.

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[1)] Military Technical Institute (VTI), Ratka Resanovića 1, 11132 Belgrade, SERBIA
Correspondence to: Nada Ilić, e-mail: nadalic67@vti.vs.rs

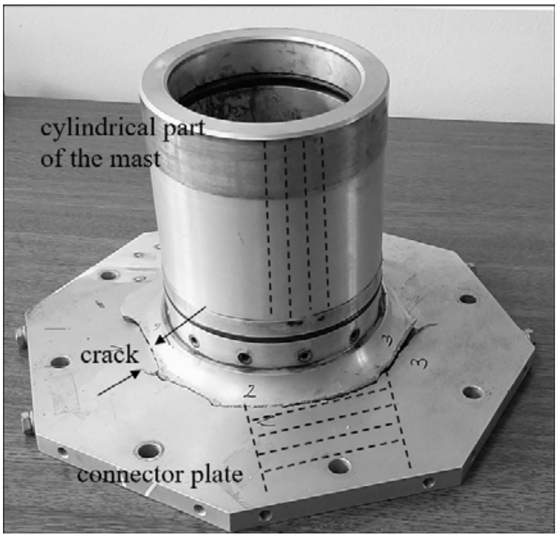



**Figure 1.** The fractured antenna mast. Dashed lines represent the location of samples for tensile testing.

Four specimens were taken from the mast in longitudinal and transverse direction from both the cylinder and connector plate, in order to examine the microstructure. The samples were prepared by grinding, polishing and electrochemical polishing in dilute perchloric acid, followed by electrochemical etching in Barker's reagent. The polished and etched surfaces were examined using light microscopy.

## Results

*Visual examination*

Visual examination of the fractured part showed that the fracture was initiated on the outer surface of the plate, close to the plate-to-cylinder radius, Figures 1 and 2. No visible plastic deformation near the fracture surface was observed. The fracture initiation point was identified by following the chevron pattern at the fracture surface, as shown in Figures 2 and 3. The chevron pattern pointing to the fracture initiation point is shown in Fig.3. Several secondary cracks were also visible, as shown in Fig.3. The crack propagated from the surface of the plate gradually in circumferential direction, around the cylinder, as well as, throughout the plate.

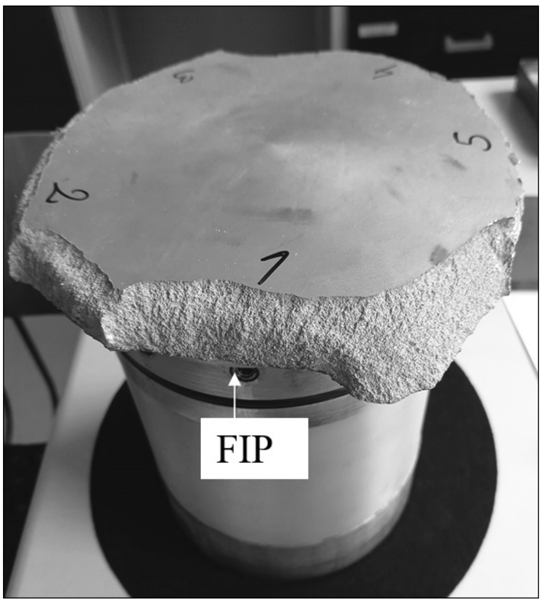



**Figure 2.** The fractured antenna mast, indicating the fracture initiation point - FIP.

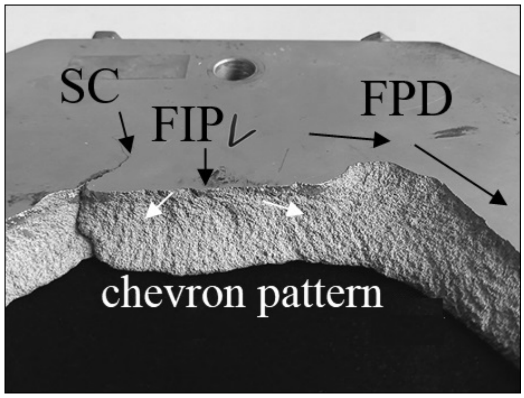



**Figure 3.** Plate-side fracture surface. FIP - fracture initiation point, FPD - fracture propagation direction, SC - secondary crack.

*Hardness*

Results of the hardness measurements of the antenna mast are given in Table 2.

**Table 2.** Hardness of the antenna mast, HB

| specimen | Hardness HB 2,5/62,5 | Average |
|---|---|---|
| cylinder | 85; 85; 87; 85; 85; 86 | **86** |
| plate | 85; 87; 86; 86; 87; 85 | **86** |

*Tensile properties*

The average values of the yield strength (YS), ultimate tensile strength (UTS) and elongation ($A_5$) observed during tensile testing of specimens taken from the antenna mast are shown in Table 3. Characteristic stress-strain curves are shown in Fig.4. The diagrams indicate that the fracture occurs immediately after reaching the maximum force, with no posthomogenous elongation observed.

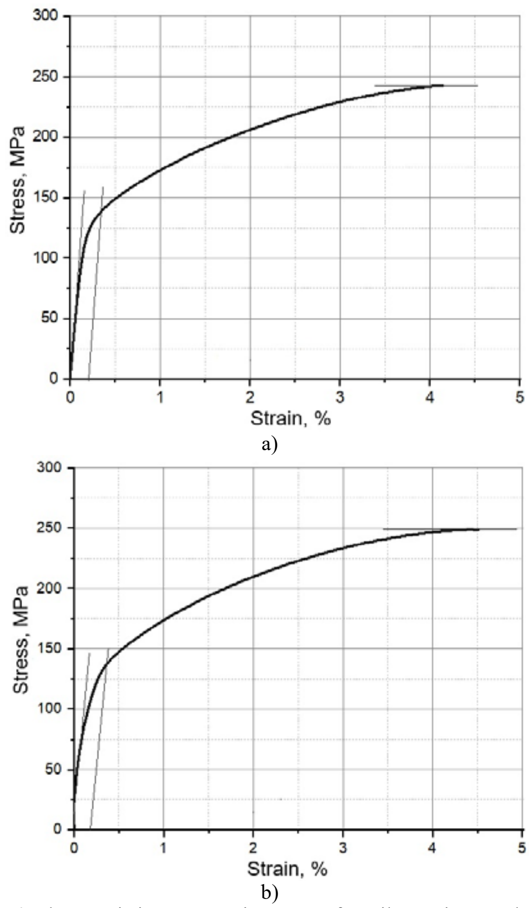



**Figure 4.** Characteristic stress-strain curves of tensile specimens taken from (a) the cylindrical part, (b) the connector plate of the antenna mast.

**Table 3.** Results of tensile tests.

| specimen | YS [MPa] | UTS [MPa] | $A_5$ [%] |
|---|---|---|---|
| cylinder | **139** | **241** | **4.0** |
| plate | **138** | **249** | **3.9** |

*Fractography*

SEM analysis of the fracture surface of tested tensile samples revealed areas of transcrystalline fracture alongside with dimple areas, fractured coarse particles, as well as porosity with visible dendrites Figures 5-7.

*3.5. Electrical conductivity*

The results of electrical conductivity measurements of the connector plate are given in Table 4.

**Table 4.** Electrical conductivity of the connector plate

| %IACS | | | | | Aver. %IACS |
|---|---|---|---|---|---|
| 41.10 | 40.93 | 40.78 | 40.72 | 40.74 | **40.85** |

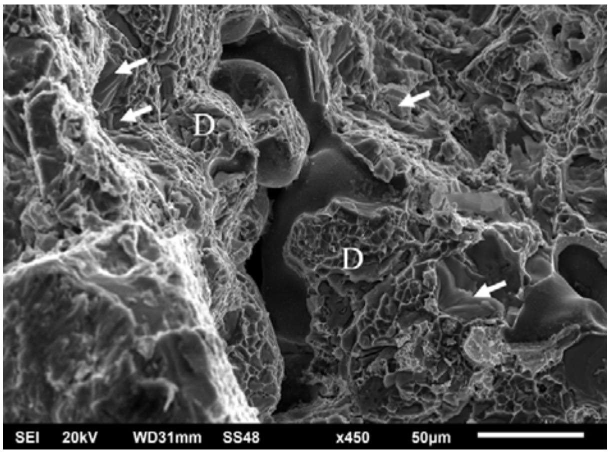



**Figure 5.** Fracture surface of tensile specimens as observed by scanning electron microscopy. Areas of dimpled fracture (D) Arrows indicate the fractured particles. Interdendritic porosity is visible in the middle of the microphotograph.

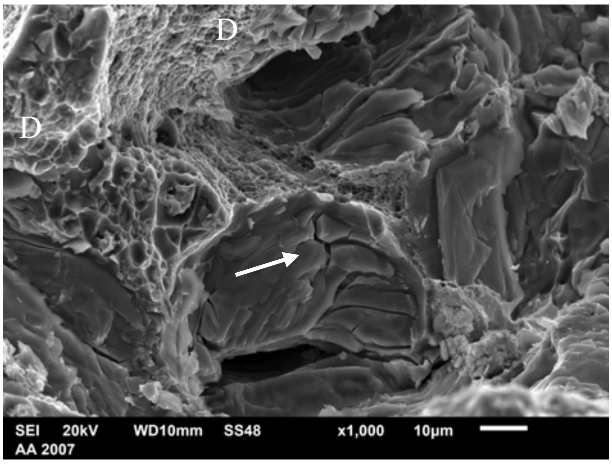



**Figure 6.** Fractured particles indicated by the arrow. Areas of dimpled fracture are also observed (D).

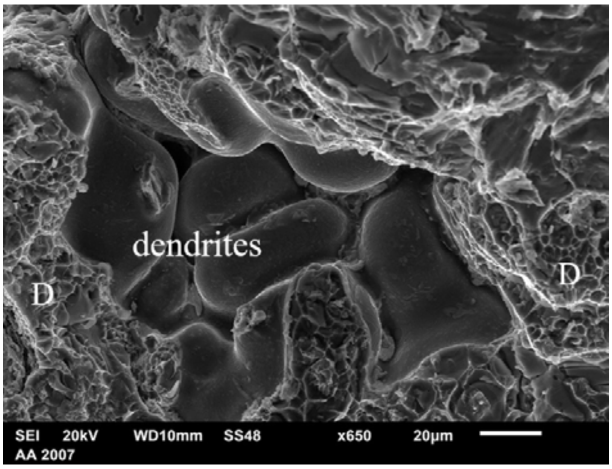



**Figure 7.** Fracture surface of the tensile specimens showing dimpled fracture (areas D) and exposed dendrites.

*Microstructure*

Fig.8 shows the microstructure of the specimens as polished. Large interdendritic porosity (IP), as well as large amount of shrinkage porosity (black spots) were observed in the cast microstructure. Fig.9 shows the microstructure as etched. A dendritic grain morphology was revealed.

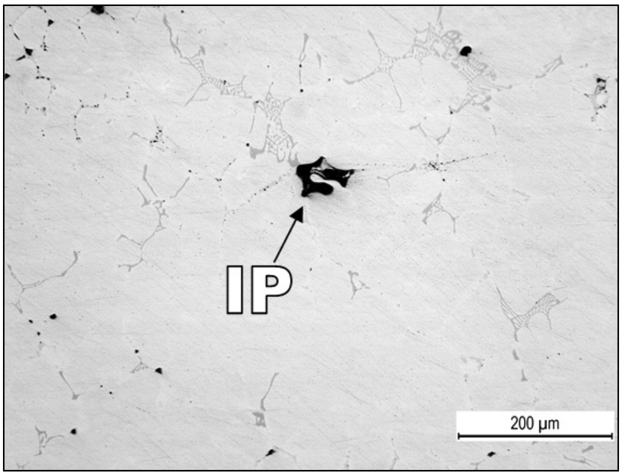
## Discussion

Visual examination of the fractured mast antenna revealed that crack was initiated on the outer surface of the plate, close to the plate-to-cylinder radius (Figures 1 and 2). It is evident that the crack was initiated in a region of high localized stress, and propagated circumferentially, around the cylinder, as well as, throughout the plate.

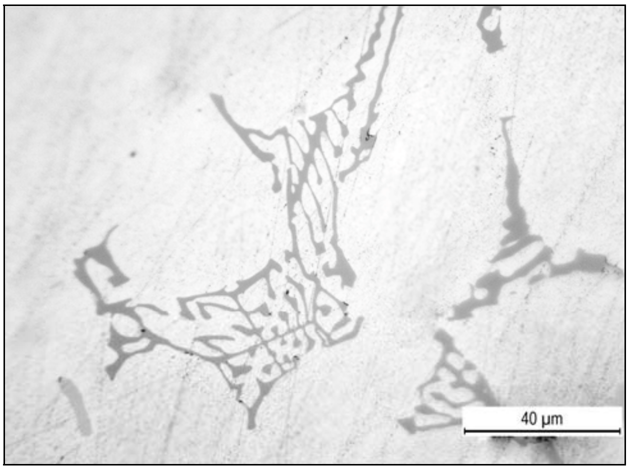
The observed chevron pattern on the fractured surface, pointing to the fracture initiation point is characteristic of macroscopic brittle behaviour of materials [8, 9].

Microstructural examination has shown that mast antenna was produced of cast material. Observed dendritic grain morphology is typical for alloys in as cast condition [10]. Interdendritic porosity was observed by the light microscopy (Fig.8), and by the SEM on the fracture surface of the tensile specimens (Fig.7).

Alloy EN AW-2007 [AlCu4PbMgMn] is a wrought type of aluminum alloy, and is not found in standards for aluminum alloy castings [5, 11, 12]. It is common that cast and homogenized bar subjected to a mechanical working, such as forging, rolling, extrusion, etc., result in uniform metallurgical structure. So, this aluminum alloy is intended to be used in form of wrought products, and it is very suitable for high machining speeds, due to Pb addition [13-16]. This alloy is not suitable to be used as cast, such as in this case. Additionally, the mechanical properties are defined for extruded bars of a maximal diameter of 250 mm [11]. The bar used to produce the mast exceeds this size limit, since it was not subjected to mechanical working.




a)




b)

**Figure 8.** Microstructure of the specimen, as polished: (a) Interdendritic porosity (IP) and shrinkage porosity (black spots), (b) shape of particles within the metal matrix. Light microscopy.

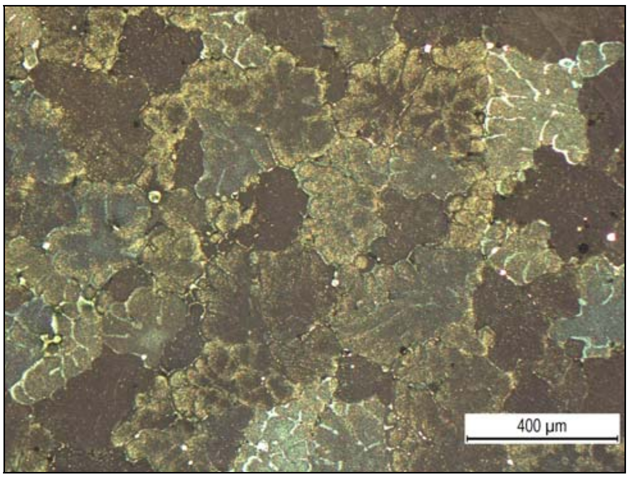



**Figure 9.** Microstructure of the specimen taken from the cylindrical part of the mast in perpendicular direction, etched. Dendritic grain morphology is present. Light microscopy under polarized light.

Therefore, it is expected that mechanical properties of the mast material were lower than required for extruded bars made of EN-AW 2007 [11]. It was confirmed by the mechanical testing (Tables 2 and 3). Hardness, as well as strength values were significantly lower than required by the standard for extruded bars (for maximal diameter of 250 mm). The results of tensile test were in accordance with the observed microstructure, as the presence of dendritic morphology and porosity contribute to the reduced mechanical properties, and the brittleness of the material.

The low tensile elongation and the lack of posthomogenous elongation (Table 3 and Figure 4), as well as the macroscopically brittle appearance of the fracture, all suggest that the material was not appropriately heat treated after casting. This is also supported by the higher electrical conductivity than the typical values given in literature for EN AW-2007 in T4 condition (18÷22 MS/m i.e. 30.96÷37.84 %IACS) [15, 16].

## Conclusion

Fracture surface analysis showed macroscopic characteristics of quasibrittle fracture.

Crack initiated on the outer surface of the plate, close to the plate-to-cylinder radius.

The temper of the used EN AW-2007 alloy is not sutable for this application. The results suggest that material of the mast was not subjected to appropriate heat treatment and mechanical working, so, applied stress during handling/raising of the antenna must, led to the rapid quasibrittle fracture.

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# Analiza loma teleskopskog komunikacionog stuba ugrađenog na vozilo

**U ovom radu su prikazani rezultati ispitivanja polomljene ploče za spajanje antenskog stuba koji su izrađeni od aluminijumske legure EN AW-2007. Cilj ispitivanja je određivanje uzroka nastanka loma koji se dogodio pri podizanju antene. Ispitani su: hemijski sastav, mikrostruktura, električna provodljivost, zatezne karakteristike i merenje tvrdoće u cilju utvrđivanja kvaliteta materijala. Uzorci antene su vizuelno pregledani, a prelomna površina je ispitana na skenirajućem elektronskim mikroskopom. Ustanovljeno je da se lom odvijao velikom brzinom bez vidljive plastične deformacije u blizini prelomne površine, što je osobina krtog loma. Ustanovljeno je da mehaničke osobine ispitanih uzoraka antene ne zadovoljavaju minimalne vrednosti definisane standardom za ovaj materijal. Niske vrednosti čvrstoće, izduženja i električne provodljivosti legure, ukazuju da materijal nije podvrgnut odgovarajućoj termičkoj obradi, što je povrđeno mikrostrukturom analizom. Zbog loše zavarljivosti aluminijumske legure od koja je izrađen stub, nije moguća reparacija polomljene ploče antenskog stuba.**

*Ključne reči:* **legura EN AW-2007, antenski stub, fraktografija.**