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Metallic Glass Examination

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Abstract.

One of the most dynamically evolving fields within materials science and modern engineering research is the investigation of amorphous metals, more commonly referred to as metallic glasses. Owing to their unique disordered atomic structure and the resulting exceptional physical properties, metallic glasses present a wide spectrum of application opportunities in high-technology sectors, particularly in electronics, medical technology, and aerospace engineering.

The objective of the present research was to produce metallic glasses through strip casting, using two fundamental metals—aluminum and tin—as well as their alloys. The application of an exceptionally high cooling rate during the casting process enables the molten metal to solidify into a disordered, amorphous ribbon structure. This structural state imparts to metallic glasses their distinctive dual character—simultaneously metallic and glass-like— while also giving rise to material properties that differ significantly from those of the base metals.

Within the scope of this study, several alloy compositions were prepared and subsequently characterized with respect to their electrical resistance and magnetic susceptibility. The experimental data were systematically recorded, tabulated, and analyzed to evaluate the influence of varying alloying ratios on the resulting material properties. The aim of this work extends beyond the mere presentation of measurements; it seeks to elucidate the degree to which amorphous metallic ribbons diverge from their crystalline counterparts, and to explore the potential technological applications that such materials may offer for future engineering solutions.

Beyond the current findings, the long-term ambition of this research is to extend the investigation to additional metals and alloy systems. Such a comparative approach will enable broader insights and foster a more comprehensive understanding of the properties and applicability of metallic glasses. ***Keywords: metalis glass, examination, alloy***

I.INTRODUCTION

It has long been recognized that the crystalline structure formed during the cooling of metals fundamentally determines the mechanical, electrical, and magnetic properties of a given metal or alloy, as well as its resistance to environmental effects. In practice, these properties are regularly modified through so-called heat treatment processes.

Our concept is that by inducing a drastic transformation of the crystalline structure during the solidification of a molten metal or alloy, we are able to significantly influence its properties, and potentially even elicit the emergence of entirely new characteristics.

In our case, the drastic alteration of the crystalline structure means that, during cooling, the oriented crystal growth corresponding to the nucleation centers—and thus the formation of crystallites, i.e., orderly connected crystal aggregates—fails to occur. Instead, a collection of irregularly arranged atomic clusters is formed, which is referred to as an amorphous structure. Since this structural configuration is characteristic of glass, such materials are commonly termed *metallic glasses*.

II. MATERIALS AND METHOD

The technology of metallic glasses is not a recent innovation; its theoretical background has been well described, and practical knowledge is also available. As a foundation for our research, these aspects were presented by László Sajó-Bohus and Csaba Bráda in their 2023 article published in *AIS*. In this work, the authors outlined the theoretical principles of metallic glass technology, described their custom-designed cooling apparatus, and presented the tin metallic glass ribbon they produced, for which they demonstrated the amorphous structure. With this, they confirmed the functionality of the cooling device, as illustrated in Figure 1 [5].

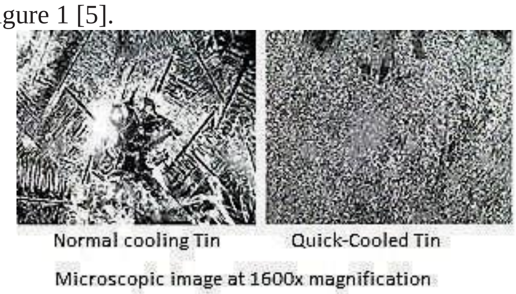

Fig. 1. Microscopic image of the base metal and the metallic glass

III. DESCRIPTION OF THE RESEARCH

As mentioned earlier, the basis of our research was the article presented in the previous chapter. With the authors' permission, we used both the cooling device and the tin metallic glass ribbon produced in their work.

Our research can be divided into two parts:

1. **Production of metallic glass ribbons from materials other than tin**
2. **Investigation and evaluation of the properties of the produced metallic glasses**

Part 1: Production of metallic glass ribbons

In our research, we focused on two base materials: aluminum and tin.

- Tin was available in the form of commercially sold solder, with a composition of 97% Sn and 3% Cu.
- Aluminum was also an industrially available machinable product, the exact composition of which was determined using spectroscopic analysis.

The chemical composition of the aluminum is shown in **Figure 2**.

Fig. 2. Chemical composition of the aluminum base material

The examinations revealed that the aluminum also contains small amounts of alloying elements (e.g., Si, Fe, Mg), which, according to the literature, may promote the formation of an amorphous structure.

The main considerations during material selection were as follows:

- Both materials are inexpensive and easily accessible.
- Both are easy to machine.
- In the electrochemical potential series, the two materials are relatively far apart.
- According to the literature, the Al/Sn alloy system has been relatively little studied, since the solubility of the two metals is limited and their crystallization tendencies are different. At the same time, this provides an opportunity to observe new and unique structural states during rapid solidification by melt-spinning. [1]

Based on data published in the literature, one of the key factors in the formation of an amorphous structure is that the alloying elements should have significant atomic radius differences and limited crystalline solubility. The Al–Sn system meets both criteria: the atoms of tin and aluminum differ considerably in size and bonding energies, and at room temperature, the two metals are only sparingly soluble in each other. This prevents the formation of a crystal lattice under rapid cooling and instead favors the development of an amorphous structure.

For the experimental investigations, we produced:

- pure tin metallic glass melt-spun ribbons from the solder material described,
- pure aluminum metallic glass melt-spun ribbons, and
- tin/aluminum alloys with different compositions.

The prepared melt-spun ribbons are shown in **Figure 3**.

Fig. 3. Prepared metallic glass melt-spun ribbons

During the production of the alloys, the raw materials were measured out according to their mass ratio. Two main compositions were investigated: the Al9oSnıo alloy (90 wt% aluminum and 10 wt% tin) and its reverse counterpart, the AlıoSn9o alloy. To ensure proper homogeneity, the materials were mechanically crushed. [2]

The experimental fabrication was carried out using a rapid solidification melt-spinning device. The molten alloy was ejected onto the rotating metal wheel of the apparatus, which provided a cooling rate of 10$–10ª K/s. Under such conditions, crystallization is suppressed, and the atoms solidify in a disordered, amorphous structure.

The mechanical strength properties of the produced alloy ribbons differed significantly. Alloys with higher aluminum content yielded longer and more uniform ribbons, whereas the tin-rich compositions (especially AlıoSn9o) proved to be extremely brittle and unsuitable for direct measurements. In these cases, the samples were prepared for testing through pressing. The powdered material was compacted into manageable pellets using a custom-made pressing tool, and these pellets were then subjected to resistance and electrical property measurements.

The raw material prepared for pressing and the final pressed products are shown in **Figure 4**.

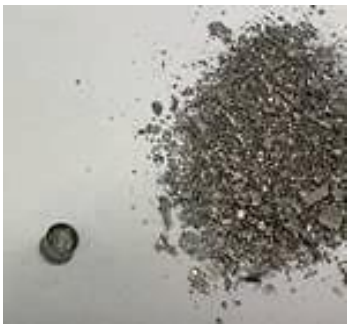

Fig. 4. Fragments of the Al–Sn alloy and pellet produced by pressing

Even with a simple manual ball press, it is possible to achieve a pressing force (Fp ≈ 8800 N for the given press) sufficient to generate a pressure on the tool surface that exceeds the yield strength of both aluminum and tin. In our case, the calculated pressing pressure exceeded 240 MPa, which is significantly higher than the yield strength of aluminum. This method therefore points towards a potential processing route for metallic glasses.

The design of the pressing tool was entirely the result of our own work. We modified the inner chamber and moving parts of the sprayer so that it was capable of compressing the fragmented material and releasing it in the form of uniform test specimens. The pre-weighed, powdered alloy was carefully placed into the tool. During pressing, the material was subjected to high pressure, causing the loose, brittle particles to consolidate into a solid, cohesive pellet.

The pellets produced by pressing were sufficiently stable and mechanically durable to be handled, attached to measuring instruments, and subjected to electrical testing. Thus, this manufacturing approach enabled measurements (such as electrical resistance tests) that could not be performed on the original brittle ribbons.

Overall, it can be stated that pressing technology was not merely an improvised solution, but a key advancement in the context of our research. It allowed us to transform extremely brittle, measurement-inadequate ribbon samples into usable test specimens. The method can also be applied to other alloys that, after rapid solidification, lack sufficient mechanical stability but whose electrical properties are of significant interest.

Part 1: Measurements

Mechanical and physical properties.
Amorphous metals generally exhibit high strength and hardness, but they are prone to brittle fracture. Tin-based alloys are particularly sensitive to cracking, so it was not surprising that the 90% Sn – 10% Al sample proved to be fragile and unmanageable in ribbon form. Even when handled, it crumbled into fragments. By contrast, pure metallic glass ribbons and aluminum-rich alloys showed better mechanical stability and were easier to handle, although the fibrous structure typical of the ribbons still led to easy fracture under tensile load.

We attempted tensile testing on the different samples, but due to the size limitations of the grips on the testing machine, the clamping system requires redesign, which could not be completed within the available timeframe. Preliminary tensile data obtained from trial experiments indicated tensile strengths that compared favorably to tabulated values for the base metals. However, these results are not yet considered exact, and therefore are not reported in detail in this paper.

Electricalproperties.
Based on the initial research hypotheses, we expected that the inhomogeneity of the amorphous structure would result in significant deviations in electrical conductivity compared to the known values of pure metals. For aluminum, high conductivity values were anticipated, while for tin, lower values are characteristic.

In alloys – particularly in the $Al_{90}Sn_{10}$ composition – we assumed that the combination of the two metals might result in new, nonlinear behavior, potentially even exhibiting an extreme positive temperature coefficient (PTC). This means that with increasing temperature, the electrical resistance could change significantly, making metallic glasses promising candidates for use in sensors and safety devices. [4] The measurement results are presented in Chapter IV, in Tables 1, 2, and 3.

Corrosionresistance.
One of the outstanding properties of amorphous metals is the absence of a crystal lattice, which significantly slows down corrosion processes. In conventional crystalline alloys, grain boundaries and lattice defects provide favorable initiation sites for oxidation and corrosion. In contrast, the structural disorder of amorphous metals results in more homogeneous chemical distribution and greater resistance against corrosive factors.

In nuclear reactor cooling systems, there is a particularly strong demand for corrosion-resistant materials. In the reactor core environment, the coolant (e.g., water, heavy water, or special fluids such as sodium or other liquid metals) operates under high temperature and pressure. Under these conditions, conventional steel alloys are prone to localized corrosion, stress corrosion cracking, and oxidation, which over time lead to wall thinning and safety risks.

According to the literature, amorphous metals (e.g., Fe-, Zr,or Al-based metallic glasses) exhibit exceptional corrosion resistance in both aqueous and oxidizing environments. This is because a thin, compact, and adherent oxide film forms quickly on their surface, effectively preventing further corrosion. This property is considered particularly valuable in nuclear energy applications, where the longterm stability of materials is crucial.

From the perspective of our research, the investigation of Al–Sn-based metallic glasses can also be interpreted in this context. Although our primary goal was to study electrical properties, the need arose to evaluate the alloys in terms of corrosion resistance as well. The well-known corrosionresistant behavior of aluminum, combined with the stabilizing effect of the amorphous structure, provides a promising foundation for such applications.

Further investigations are required to determine the extent to which the Al–Sn system can withstand the extreme conditions imposed by nuclear coolants. Nevertheless, based on the literature and our preliminary findings, it can be stated that the corrosion resistance potential inherent in the amorphous structure represents a highly promising research direction for the development of new materials used in reactor cooling circuits.

As a preliminary study, we carried out a comparative test in which the mass loss of the starting materials—tin, aluminum—and the produced metallic glasses was measured in an identical acidic medium, under 1-hour and 24-hour exposure cycles. The results are presented in **Table 4 of Chapter IV**.

IV. RESULTS

Due to the structural characteristics of metallic glasses, several distinctive properties are expected in the aluminum, tin, and alloy samples we produced. The absence of a crystal lattice and the disordered distribution of atoms result in physical and chemical properties that differ significantly from the behavior of conventional crystalline metals [3].

This statement is supported by the measurement results obtained from the individual material samples.

- **Table 1** contains the results of the measurements performed on pure aluminum metallic glass meltspun ribbons.
- **Table 2** presents the data for the $Al_{90}Sn_{10}$ metallic glass ribbons.
- **Table 3** shows the results measured on the $Al_{10}Sn_{90}$ pressed pellets.

The measured RR (Ω) value represents the actual resistance of the tested specimen, which is influenced by the geometry of the sample. For comparability, the results were recalculated into specific resistivity and conductivity values. On the basis of these specific values, the results can be directly compared to literature data for the base metals.

l (m)	A (mm²)	R (Ω)	Rfajlagos (Ω·mm²/m)	G (S·m²/mm²)
0,06 6	0,145	0,104	0,228	4,39
0,06 4	0,142	0,103	0,228	4,39
0,06 2	0,78	0,01	0,126	7,94

Table 1. Actual and specific data of the aluminum samples

Table 2. Actual and specific data of the 90% Aluminum – 10% Tin samples

The $Al_{90}Sn_{10}$ alloy ribbons exhibited extremely low resistance at room temperature (~0.03 Ω). However, when the sample was exposed to sunlight excitation, the resistance increased drastically to 46.8 Ω. This extreme Positive temperature coefficient (PTC) behavior is particularly promising for applications in sensors and safety devices.

l (m)	A (mm²)	R (Ω)	Rspecific heat (Ω·mm²/m)	G (S·m²/mm²)
0,06	0,104	0,019	0,126	7,94
0,044	0,14	0,04	0,127	7,87
0,069	0,14	0,012	0,069	14,49
		0,15	0,086	11,62

Table 2. Actual and specific data of the 90% Al and 10% Sn samples

l (m)	A (mm²)	R (Ω)	Rspecific heat (Ω·mm²/m)	G (S·m²/mm²)
0,003	19.62	0,018	117.72	0,00849

Table 3. Actual and specific data of the 10% Al and 90% Sn samples

1. Table 3. Actual and specific data of the 10% Aluminum – 90% Tin sample.

2. The pressed sample of the $Al_{10}Sn_{90}$ alloy also exhibited interesting behavior when excited by sunlight. The measured resistance value dropped to 0.002 Ω, which reduced the specific resistivity to 13.08 Ω·mm²/m.
3. Results of corrosion tests.

aqueous solution of phosphoric acid with 0.1 m/m % surfactant mixture			
	initial mass (g)	mass after 1 hour (g)	mass after 24 hours (g)
Al base metal.			
$Al_{90}Sn_{10}$	3,0	3,0	3,0
Al metallic glass	7,0	7,0	7,0
Sn base metal.	11,0	11,0	11,0
Sn metalic glass			

Table 4. Corrosive property

Significant foaming was observed in aluminum and Al/Sn alloys, indicating material loss. The accuracy of the measuring device is 1 g. The measurement must be repeated with a device of higher accuracy.

V. DISCUSSION AND CONCLUSION

In the course of our experiments, we successfully produced aluminum, tin, and aluminum–tin-based metallic glass ribbons, as well as stabilized pressed specimens. The results clearly demonstrated that the melt-spinning technology is suitable for the formation of amorphous structures. At the same time, the alloy composition had a decisive influence on the mechanical stability and measurability of the samples.

The aluminum ribbons proved to be stable and easy to handle, as expected. Resistance measurements showed a positive temperature coefficient, consistent with metallic conduction models reported in the literature. Tin ribbons were also successfully produced but turned out to be mechanically weaker. Their electrical properties exhibited only moderate variation with temperature, and no measurable magnetic response was observed.

Among the alloys, the Al90Sn10 composition displayed outstanding properties: its resistance was extremely low at room temperature, then increased drastically upon heating. This pronounced PTC effect may be of practical interest in industrial applications, such as temperature sensors and safety devices.

In contrast, the Al10Sn90 alloy was extremely brittle, making it unsuitable for measurement in ribbon form. Pressed pellets provided a partial solution to the problem of measurement, though their mechanical weakness remained a limiting factor.

The investigations highlighted that Al–Sn alloys produced by rapid solidification are promising but also present technological challenges. In line with general properties of metallic glasses mentioned in the literature (high strength, corrosion resistance, soft magnetic behavior), our experiments also confirmed the potential for corrosion resistance and unique electrical responses.

Conclusions:

- Aluminum and tin can successfully be produced in amorphous structure by melt-spinning.
- The aluminum-rich alloy (Al90Sn10) is particularly promising due to its extreme PTC behavior.
- The tin-rich alloy (Al10Sn90) requires pressing because of its mechanical instability, which provided a partial solution to its measurability.

In the future, it will be worthwhile to investigate possibilities for further increasing the mechanical strength, to test new alloying ratios, and to carry out detailed corrosion tests. In addition, alternative heat treatment and pressing technologies may also contribute to expanding the industrial applicability of the Al–Sn system.

- Based on our investigations, Al–Sn metallic glasses may in the future find applications in sensors, safety systems, and potentially in the energy industry, where corrosion resistance is required, such as in the cooling circuits of nuclear reactors.
- Future research should focus on improving mechanical strength, exploring new alloy compositions, and conducting detailed corrosion assessments. Furthermore, different heat treatment and pressing technologies could enhance the potential of the Al–Sn system for industrial use.

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