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Cold roll bonding of Al/ μ M/Al and μ M/Al/ μ M for wide frequency magnetic shielding

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Abstract:

This work studies the interest of Al / μ M /Al and μ M /Al / μ M metal composite obtained by cold roll bonding for magnetic shielding. Aluminum was chosen to form the composite because of its electrical conductivity and low mass density, making it possible to obtain a metal composite with a mass density lower than that of Mumetal (μ M). First the shielding effectiveness of the metal composite is investigated. Then, the annealing effect on their shielding effectiveness is highlighted. Finally, the impact of plastic deformation due to rolling is presented. The results of this work show that at low frequencies ($f < 500$ Hz), the shielding effectiveness of the metal composite is on average 6% lower than that of Mumetal. Yet, at high frequencies ($f > 1$ kHz), an increase of up to 70 % in the shielding effectiveness of the metal composite compared to Mumetal is noticed.

Keywords: Magnetic shielding, metal composite, cold roll bonding

1 Introduction

The constantly increasing number of electronic systems within the same electromagnetic environment poses a problem of electromagnetic compatibility and raises issue of the impact on the health of living being exposed to the resulting electromagnetic field [1, 2]. To limit interferences between various electronic systems, electromagnetic shielding can be used. This involves an increase in the onboard electronic equipment mass and/or volume because of the shielding system and the need to have efficient shielding over a wide frequency range. At low frequencies, nickel-iron alloys such as Mumetal (μ M) allow achieving good shielding effectiveness thanks to their high magnetic permeability. However, at high and very high frequencies, it is rather good conductive metals such as copper and aluminum (Al) which make it possible to reach a better shielding effectiveness. Therefore, it appears advantageous to combine materials with high magnetic permeability to materials with good conductivity to obtain a composite metal making it possible to ensure good shielding effectiveness over a wide frequency range.

The studies of Hoburg *et al.* [3] revealed the interest in alternating conductive layers and magnetic layers to elaborate a multilayer for quasistatic magnetic shielding. Recent studies have focused on the feasibility by roll bonding of aluminum-steel metal composites for magnetic shielding, by studying the compromise between shielding effectiveness and the adhesion of metal sheet layers [4, 5]. Yamazaki *et al.* [6] have shown the advantage of building an anechoic chamber for very low frequency magnetic shielding ($f < 100\text{Hz}$) by stacking layers of μM and aluminum. In their study, given that the multilayer results from a superposition of the layers, the impact of a possible plastic deformation on the metal composite was not studied. The present study proposes to determine the interest of metal composite $\mu\text{M}/\text{Al}/\mu\text{M}$ and $\text{Al}/\mu\text{M}/\text{Al}$ obtained by cold roll bonding for low frequency magnetic shielding (1Hz to 10kHz). The novelty in this work is to determine the impact of plastic deformation resulting from roll bonding on the shielding effectiveness of such composites.

2 Materials and Methods

2.1 Materials

The commercial μM (FeNi80, $\mu_r > 2000$, $\sigma = 1.67 \text{ MS/m}$) in annealed state at 800°C for 1 hour under hydrogen is chosen. This choice is motivated by the high magnetic permeability of this material. Aluminum (EN AW-Al99.0, $\mu_r = 1$, $33 \text{ MS/m} < \sigma < 35.5 \text{ MS/m}$) has been chosen for its high electrical conductivity. The sheets of these materials were cut into samples measuring 3 cm by 3 cm and then cleaned with acetone.

2.2 Cold roll bonding process

Rolling is an industrial manufacturing and shaping process by plastic deformation of metals [7]. This plastic deformation is obtained by continuous passage of the metal between two cylinders of a rolling mill. These apply compression to the metal while reducing its thickness and thus leading to its elongation. Cold roll bonding is the simultaneous rolling at room temperature of several sheets stacked in order to achieve, under certain conditions, their adherence [8]. Figure 1 shows the process of roll bonding. Before rolling, the surfaces of the sheets are brushed using a rotating stainless-steel brush to facilitate the sheets adherence through the fragmentation-extrusion-bonding mechanism [9]. Indeed, the brushing of the surface of the sheets allows a strain hardening on the surface which facilitates adhesion of sheets during rolling.

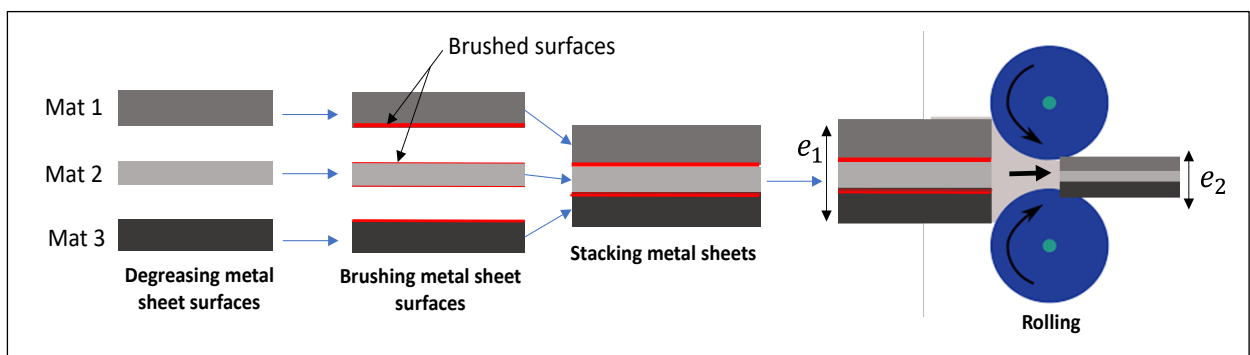


Fig.1: Roll bonding process

Figure 2 shows a longitudinal cross-section of the metal composites $\mu\text{M}/\text{Al}/\mu\text{M}$ and $\text{Al}/\mu\text{M}/\text{Al}$ obtained by cold roll bonding with a reduction rate of respectively 78% and 53%. For comparison purpose, both

metal composites have approximately an equal total thickness of aluminum and μM . The thickness of each layer is as follow: $\mu\text{M}(170\mu\text{m})/\text{Al}(65\mu\text{m})/\mu\text{M}(165\mu\text{m})$ and $\text{Al}(41\mu\text{m})/\mu\text{M}(331\mu\text{m})/\text{Al}(28\mu\text{m})$. All samples have a total thickness of about $400\mu\text{m}$.

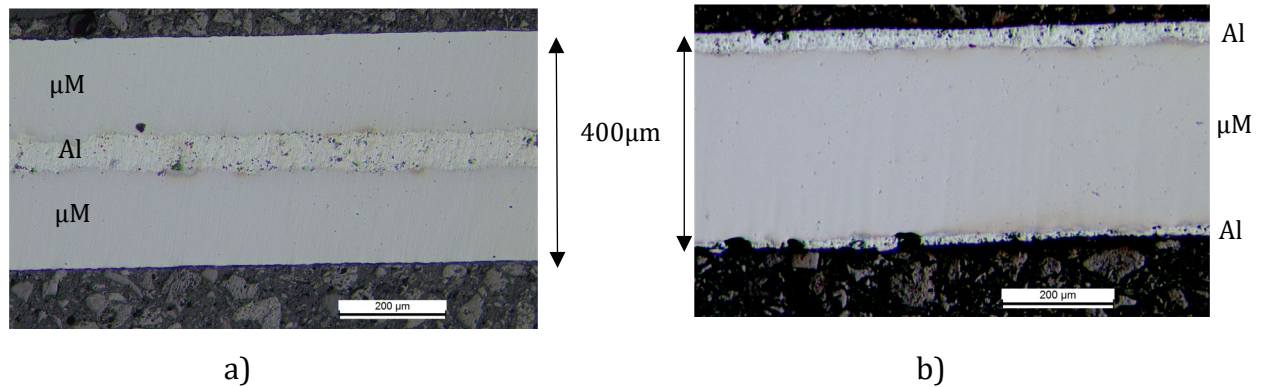


Fig.2: Longitudinal cross-section of a) $\mu\text{M}/\text{Al}/\mu\text{M}$ and b) $\text{Al}/\mu\text{M}/\text{Al}$

2.2 Magnetic shielding effectiveness measuring bench

The test bench used for measuring the shielding effectiveness of the samples is shown in Figure 3. It consists of a signal generator supplying a coil which generates a sinusoidal disturbing magnetic field whose attenuation by the material defines its shielding effectiveness according to the relationship:

$$SE(\text{dB}) = 20 \log_{10} \frac{H_{unshield}}{H_{shield}} \quad (1)$$

where $H_{unshield}$ is the magnetic field measured by the probe in the absence of the shield and H_{shield} the magnetic field measured in the presence of the shield.

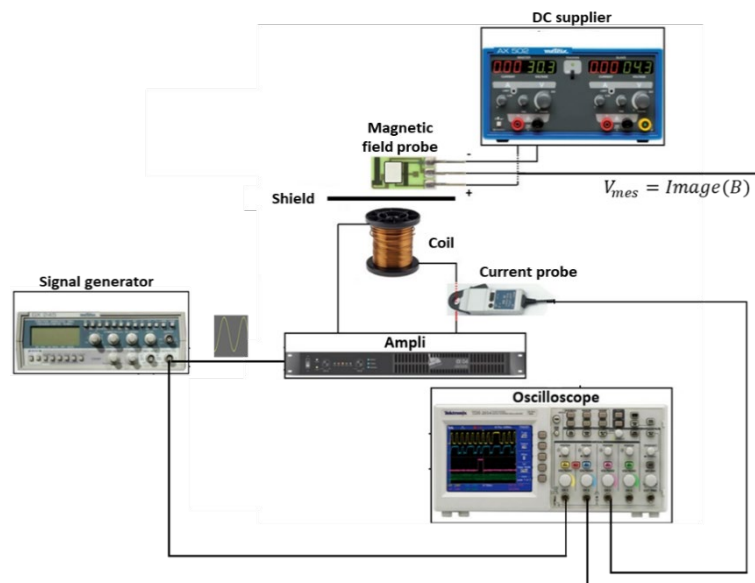


Fig.3: Illustration of magnetic shielding effectiveness measuring bench

3 Results and discussion

Figure 4a presents the shielding effectiveness of the two metal composites compared to that of a layer of μM . For $f < 1 \text{ kHz}$, the μM layer has a shielding effectiveness 6% greater than that of the two metal

composites. This is explained by its high magnetic permeability than the equivalent magnetic permeability of the composite metals. Indeed, at very low frequencies, the disturbing magnetic field is attenuated thanks to the ability of the magnetic material to channel the magnetic flux. The magnetic permeability of a material characterizes its ability to channel a magnetic flux. Thus, the higher the magnetic permeability of a material, the better its shielding efficiency at low frequencies. For $f > 1$ kHz, the sample $\mu\text{M}/\text{Al}/\mu\text{M}$ has the highest shielding effectiveness thanks to the aluminum layer which increases the intensity of the magnetic flux opposing the flux of the disturbing magnetic field. Indeed, at medium and high frequencies, the eddy currents induced in a metal sheet generate a magnetic field flux opposing the flow of the disturbing magnetic field, thus improving the shielding effectiveness. The intensity of the induced eddy currents essentially depends on the frequency of the disturbing field, the electrical conductivity of the material and the thickness of the shielding. Thus, the higher the electrical conductivity of the material, the greater the attenuation of the disturbing magnetic field. The difference in shielding effectiveness between the two metal composites for $f > 500$ Hz is explained by the fact that the position of the aluminum layer in the $\mu\text{M}/\text{Al}/\mu\text{M}$ structure maximizes the magnetic field flux opposing the flux of the disturbing field. This is not the case for the $\text{Al}/\mu\text{M}/\text{Al}$ structure.

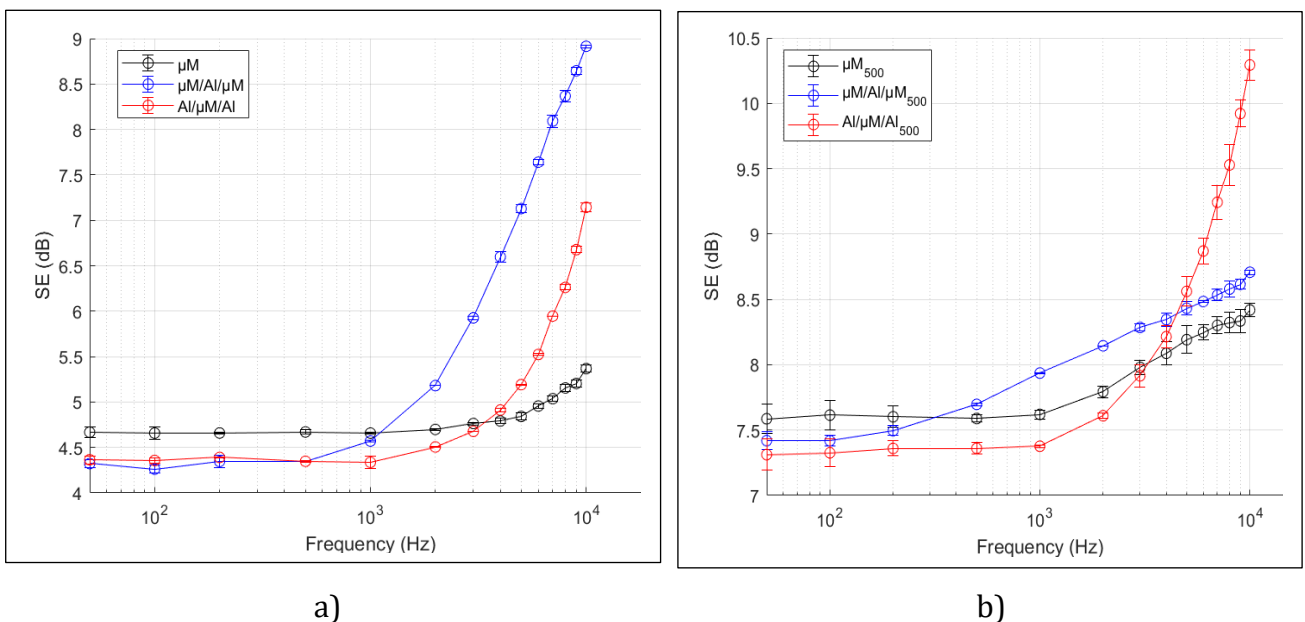


Fig. 4: Samples shielding effectiveness versus frequency: a) samples not annealed after roll bonding.
b) samples annealed at 500°C for 2 hours after roll bonding

After annealing at 500°C for two hours under argon, an increase of about 65% in the shielding effectiveness of the three samples is observed as shown in Figure 4b. This increase is explained by the increase in the magnetic permeability of the μM due to the reduction of its internal strain. Indeed, during the roll bonding, the size of the μM grains is reduced and its internal strain increases leading to the reduction of its relative permeability [10]. Figure 5 shows the effect of plastic deformation on shielding effectiveness of μM sheet due to its rolling with a reduction rate of 50%.

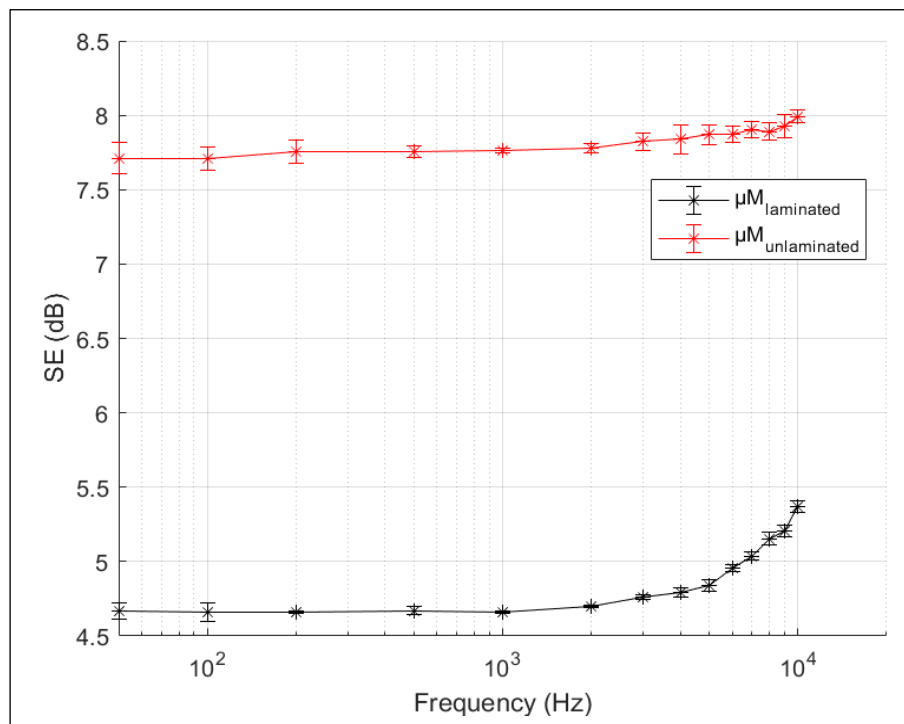


Fig. 5: Effect of rolling μM sheet on its shielding effectiveness

Conclusion

The metal composite combining Mumetal and aluminum can be elaborated by roll bonding in order to significantly attenuate a disturbing magnetic field for $1 \text{ kHz} < f < 10 \text{ kHz}$. However, the plastic deformation due to the rolling of the sheets causes the reduction of the equivalent magnetic permeability of the metal composite and therefore the reduction of its shielding effectiveness. Annealing after rolling of such a metal composite is therefore essential. However, the low melting temperature of aluminum and the risk of aluminum diffusion in the μM limits the annealing temperature.

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