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KOMPOZYTY
COMPOSITES

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COMPRESSION BEHAVIOUR OF MAGNESIUM-EUTECTIC MIXTURE LAYERED COMPOSITE

Magnesium-eutectic mixture ($Mg_{17}Al_{12}$ and solid solution of aluminium in magnesium) layered composite has been prepared by sintering magnesium and aluminium sheets. Samples of the composite with different thickness ratio of the magnesium layers to the layers containing eutectic mixture were examined in the compression test. Experiment was performed to compare the strain behaviour and strength properties of composites loaded parallel or perpendicular to the layers. According to microscopic observations in both cases crack initiation occurred in the layers of eutectic mixture. Cracks were spreading along or across the layers depending on the load direction. The composites loaded parallel to layers exhibit extremely low plasticity because with cracking of layers containing eutectic mixture, catastrophic fracture of specimen was observed. Composites compressing perpendicular to layers show some plastic flow to failure despite splitting of the eutectic mixture layers. In this case cracks of layers containing eutectic mixture were arrested at the magnesium. With increase of thickness ratio layers containing eutectic mixture to layers of magnesium increases the yield strength of composites. During compression test delamination of the layers of composite was not observed.

Keywords: **metal-intermetallic layered composite, magnesium, compression test**

KOMPOZYT WARSTWOWY MAGNEZ-EUTEKTYKA ODKSZTAŁCANY W PRÓBIE ŚCISKANIA

Kompozyt magnez-eutektyka (mieszanina faz $Mg_{17}Al_{12}$ i roztworu stałego aluminium w magnezie) został wykonany poprzez spiekanie arkuszy magnezu i aluminium. Próbki kompozytu o różnym stosunku grubości warstw magnezu do grubości warstw o strukturze eutektyki poddane zostały próbie ściskania. Badania przeprowadzono w celu porównania mechanizmu odkształcenia i własności wytrzymałościowych kompozytów obciążanych równolegle i prostopadle do warstw. W obydwu przypadkach inicjacja pęknięć następowała w warstwach faz o strukturze eutektyki. Pęknięcia przebiegały wzdłuż lub w poprzek tych warstw w zależności od kierunku obciążenia. Kompozyty obciążane równolegle do warstw charakteryzowały się wyjątkowo niską plastycznością. Pęknięcia pojawiające się w warstwach o strukturze eutektyki powodowały natychmiastowe zniszczenie próbki. Kompozyty ściskane prostopadle do warstw o strukturze eutektyki wykazywały niewielkie odkształcenie plastyczne pomimo pęknięć pojawiających się w warstwach o strukturze eutektyki. W tym przypadku pęknięcia warstw eutektyki blokowane były na granicy z magnezem. Stwierdzono wzrost granicy plastyczności kompozytów wraz ze zwiększaniem się grubości warstw o strukturze eutektyki w stosunku do grubości warstw magnezu. Podczas próby ściskania nie zaobserwowano delaminacji kompozytu.

Słowa kluczowe: **kompozyty warstwowe metal-fazy międzymetaliczne, magnez, próba ściskania**

INTRODUCTION

It has been shown in the last years that layered metal-intermetallic phases composites can be prepared by reactive sintering alternately stocked foils of two different metals [1-7]. Basing on this method the Ni--intermetallics [1-3], Fe-intermetallics [1-3], Ti-intermetallics [1-6] and Cu-intermetallics [7] layered composites have been fabricated. Method of intermetallic phases synthesis from two elemental metals we were used for formation of Mg-intermetallic (magnesium--aluminium) phases composite. Pocket of magnesium and aluminium sheets that were stocked in alternating sequence was heated at pressure to obtain initial diffusion bonding between metals. Process at the magnesium-aluminium interface that was passing with the liquid phase contribution at the temperature 445°C was prolonged till all the aluminium sheets were fully exhausted and transformed together with part of magnesium sheets into a liquid phase. After of the liquid phase solidification composite with layers of magnesium and layers containing product of Mg-Al reaction was obtained. This fabrication method allow to prepare composites with any thickness ratio of the magnesium layers to the layers of magnesium-aluminium phases. Details concerning formation of the composite are given in [8]. In this work results of compression test of the composite were presented. To obtain essential informations concerned mechanical behaviour and failure mode, samples of composite were loaded parallel and perpendicular to the composite layers.

EXPERIMENTAL PROCEDURE

Using method that was presented above composites with the thickness ratio of the magnesium layers to the layers of the magnesium-aluminium phases 5:1, 1.2:1 and 0.3:1 were prepared. It was found previously [8] that dominant part of the microstructure of synthesized layers of composite is the eutectic mixture of the $Mg_{17}Al_{12}$ compound and solid solution of aluminium in magnesium. Microstructure of the composite with the 1.2:1 thickness ratio of the magnesium layers to layers of the magnesium-aluminium phases is shown in Figures 1 and 2. Also thin layers of the solid solution of aluminium in magnesium (marked δ in Fig. 2) in the neighbourhood of the magnesium layers of composite were revealed. It should be added that the structure of synthesized layers of composites was independent of the thickness ratio of the starting Mg and Al sheets.

Compression test was carried out at the room temperature using an INSTRON testing machine. Cubic samples with dimension of 10 mm were deformed at a strain rate of $5.5 \cdot 10^{-4}$ s^{-1}.

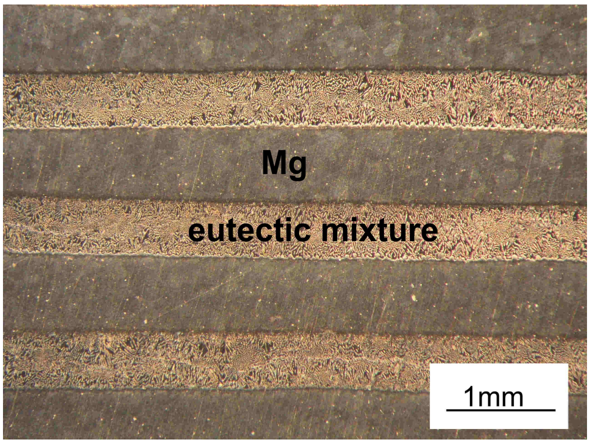

Fig. 1. Microstructure of the layered composite with the 1.2:1 thickness ratio of the magnesium layers to the layers of the magnesium-aluminium phases

Rys. 1. Mikrostruktura kompozytu warstwowego o stosunku grubości warstw magnezu do grubości warstw faz magnezowo-aluminiowych wynoszącym 1,2:1

The samples were loaded parallel and perpendicular to the layers direction (Fig. 3). Lateral walls of specimens were mechanically polished to observe slip traces by means of a light microscope. Also scanning electron microscope JSM 5400 was used to the cracking examination.

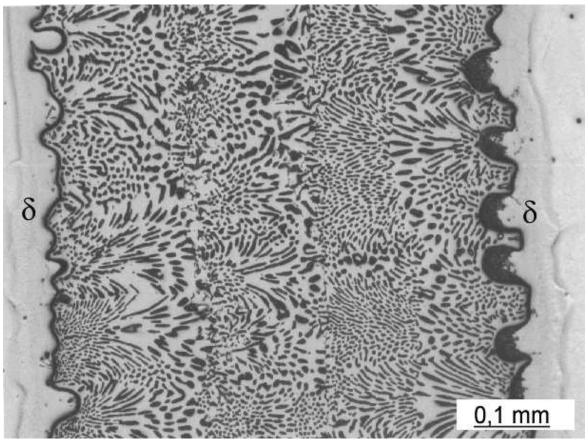

Fig. 2. Microstructure of the composite layer containing eutectic mixture. The thickness ratio of the Mg layers to the layers containing eutectic mixture 1.2:1

Rys. 2. Mikrostruktura warstwy faz magnezowo-aluminiowych w kompozycie o stosunku grubości warstw magnezu do grubości warstw o strukturze eutektyki 1,2:1

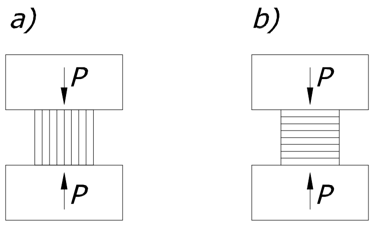

Fig. 3. Loading configuration: a) compression parallel to the layers of composite; b) compression perpendicular to the layers of composite

Rys. 3. Schemat obciążenia: a) obciążenie ściskające równoległe do warstw kompozytu; b) obciążenie ściskające prostopadłe do warstw kompozytu

RESULTS AND DISCUSSION

Mechanical behavior and strength properties of magnesium-eutectic mixture phases composite were strongly dependent on the compressive loading direction and on the volume fraction of the eutectic mixture in composite expressed by the thickness ratio of the magnesium layers to thickness of the layers containing eutectic mixture. Figure 4 shows load-displacement curves as received from the compression test for load direction parallel to laminates. The yield strength corresponding to the thickness ratio of Mg layers to the layers containing eutectic mixture 5:1; 1.2:1; 0.3:1 are 62, 118, 194 MPa respectively.

The damage mechanism for all the composites compressed parallel to layers was similar. Figure 5 shows fractured sample with thickness ratio of the Mg layers to the layers containing eutectic mixture 1.2:1. Cracks observed in synthesized layers of composite are propagating parallel to the load direction or are running at some angles to the load direction (Fig. 6). These layers of composite are stiffer compared to magnesium layers so that they are carrying all the load until fracture. Till the global fracture of specimen, only very limited plastic deformation can be initiated in some magnesium grains of preferred orientation. Catastrophic fracture of the specimen involves severe plastic deformation of the magnesium layers localized in the vicinity of the fracture (Fig. 5). Sudden drop of the load, especially for composites with the thin of magnesium layers was observed (Fig. 4).

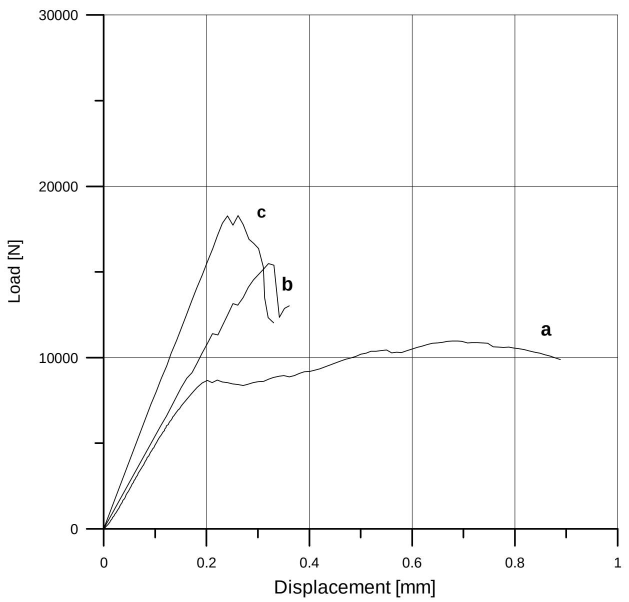

Fig. 4. Load-displacement curves for composites with the thickness ratio of the Mg layers to the layers containing eutectic mixture 5:1 (a), 1.2:1 (b) and 0.3:1 (c). Compression parallel to the layers of the composite

Rys. 4. Wykresy siła-przemieszczenie dla kompozytów o stosunku grubości warstw magnezu do grubości warstw zawierających eutektykę 5:1 (a), 1,2:1 (b), 0,3:1 (c). Próbki były ściskane równolegle do warstw kompozytu

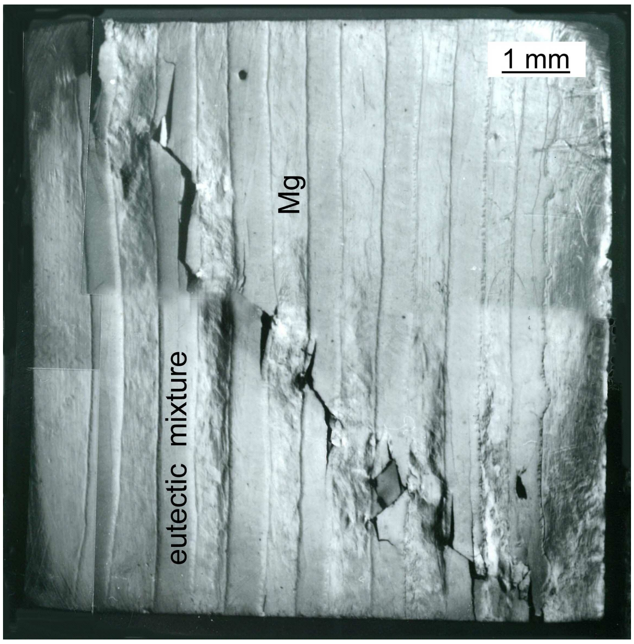

Fig. 5. Micrograph of the sample stressed parallel to the layers of composite. The thickness ratio of the magnesium layers to the layers containing eutectic mixture 1.2:1

Rys. 5. Mikrofotografia próbki ściskanej równolegle do warstw kompozytu. Stosunek grubości warstw magnezu do grubości warstw zawierających eutektykę 1,2:1

It should be noticed that composites were deformed without any delamination at the magnesium interface. Absence of delamination indicates on very good bonding between the magnesium and layers that were synthesized from magnesium and aluminium metals.

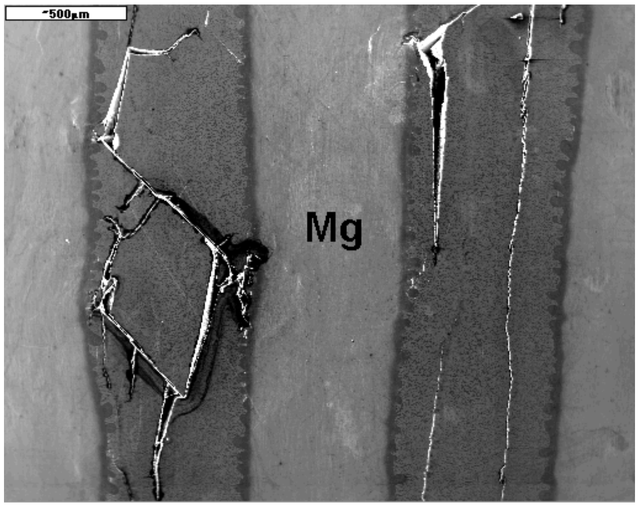

Fig. 6. Scanning electron micrograph showing cracks in layers of composite containing eutectic mixture. Layers of composite parallel to the load direction. The thickness ratio of the Mg layers to the layers containing eutectic mixture 1.2:1

Rys. 6. Mikrofotografia skaningowa przedstawiająca pęknięcia w warstwach kompozytu zawierających eutektykę. Warstwy kompozytu równoległe do kierunku obciążenia. Stosunek grubości warstw magnezu do grubości warstw zawierających eutektykę 1,2:1

Figure 7 shows load-displacement curves as received from the compression test for load direction perpendicular to laminates.

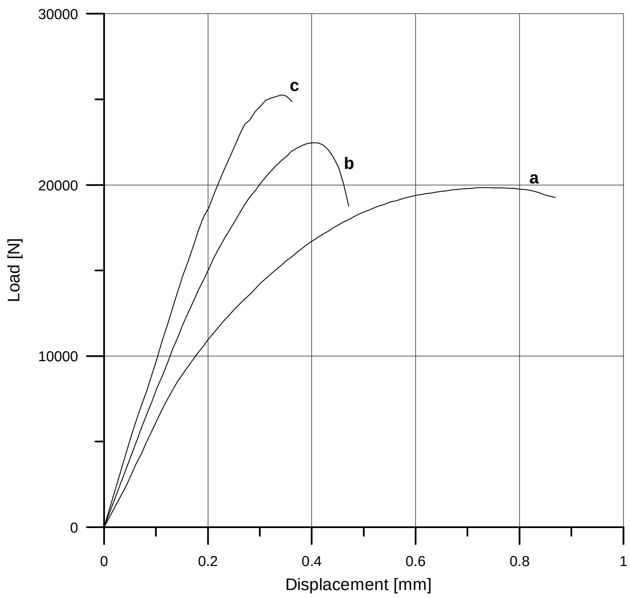

Fig. 7. Load-displacement curves for composites with the thickness ratio of the Mg layers to the layers containing eutectic mixture 5:1 (a), 1.2:1 (b) and 0.3:1 (c). Compression perpendicular to the layers of composite

Rys. 7. Krzywe siła-przemieszczenie dla kompozytów o stosunku grubości warstw magnezu do grubości warstw zawierających eutektykę 5:1 (a), 1,2:1 (b), 0,3:1 (c). Próbki kompozytu były ściskane prostopadle do warstw

Splitting of layers containing eutectic mixture was also parallel to the load direction but cracks were running across the layers (Figs. 8, 9). Because cracks were arrested at the magnesium interface, sample was prevented from the global fracture. The yield strength calculated from the load-displacement curves was 80, 138, 150 MPa for composites with thickness ratio of the magnesium layers to the layers containing eutectic mixture 5:1; 1.2:1 and 0.3:1 respectively.

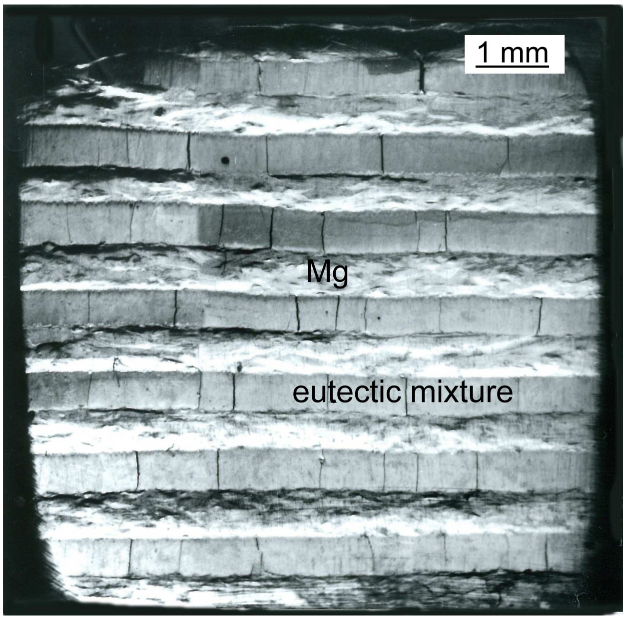

Fig. 8. Micrograph of the sample stressed perpendicular to the layers of composite. The thickness ratio of the magnesium layers to the layers containing eutectic mixture 1.2:1

Rys. 8. Mikrofotografia próbki ściskanej prostopadle do warstw kompozytu. Stosunek grubości warstw magnezu do grubości warstw zawierających eutektykę 1,2:1

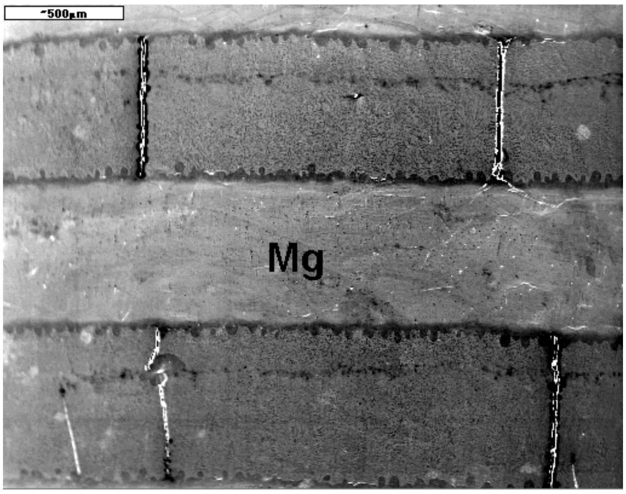

Fig. 9. Scanning electron micrograph showing cracks in layers of composite containing eutectic mixture. Layers of composite perpendicular to the load direction. The thickness ratio of the Mg layers to the layers containing eutectic mixture 1.2:1

Rys. 9. Mikrofotografia skaningowa przedstawiająca pęknięcia w warstwach kompozytu zawierających eutektykę. Warstwy kompozytu prostopadłe do kierunku obciążenia. Stosunek grubości warstw magnezu do grubości warstw zawierających eutektykę 1,2:1

It is interesting that this mode of failure was also observed for brittle layers of tensile tested metal-intermetallic phases composites [3]. In fact, during the compression, layers of composite are also subjected to tensile deformation in the direction that is perpendicular to the global load of specimen. With increase of the load further increases the cracks number in the layers of intermetallics.

As a result layers of magnesium have gradually undergone the external stress and strain hardening of the specimen that is produced due to plastic deformation of the magnesium layers was observed (Fig. 7). The essential feature of plastic flow is strain localization of the magnesium layers. Figure 10 shows bands of localized deformation (shear bands) spreading between opposite cracks in the layers of composite containing eutectic mixture.

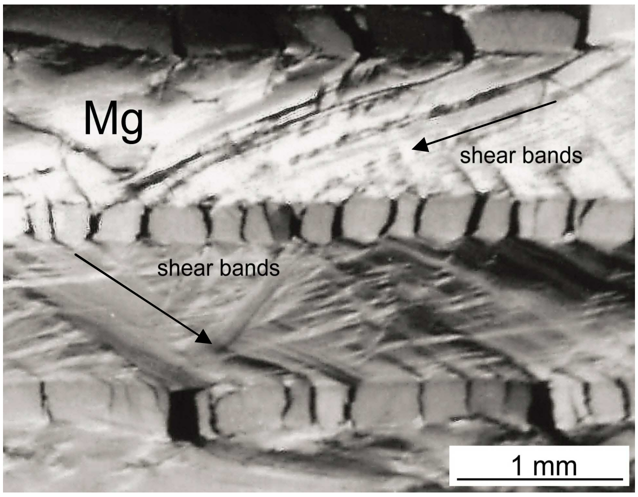

Fig. 10. Cracks and propagation of the shear bands during compression of composite perpendicular to the layers. The thickness ratio of the Mg layers to the layers containing eutectic mixture 5:1. Optical microscope

Rys. 10. Pęknięcia oraz propagacja pasm poślizgu w kompozycie ściskanym prostopadle do warstw. Stosunek grubości warstw magnezu do grubości warstw zawierających eutektykę 5:1. Mikroskop optyczny

Similar mechanical performance and damage evolution has been observed in the compression tested titanium-Al_3Ti [9, 10] and copper-intermetallics [11] layered composites. All the materials were laminates consisting layers of plastic metals and hard but brittle layers containing intermetallic phases.

CONCLUSIONS

1. Composite was failed due to cracking of layers containing eutectic mixture.
2. Cracks along the layers and cracks inclined to the layers of composite containing eutectic mixture were observed when load direction was parallel to the layers of composite. For composite loaded perpendicu-

lar to the layers cracks are spreading across the layers of composite.

3. Cracking of composite layers containing eutectic mixture was followed by extensive shear banding in the magnesium layers of composite.
4. Delamination along the magnesium-eutectic mixture interface was not observed till the fracture of composite.
5. The composite yield strength value increases with increase of the thickness ratio the layers containing eutectic mixture to the layers of magnesium.

Acknowledgement

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