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Dry sliding wear behaviour of a conventional and recycled high pressure die cast magnesium alloys

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Abstract

The dry sliding wear behaviour of a conventional and a recycled magnesium alloy produced by high pressure die casting was assessed by ball-on-disc tests under three different loads at a constant sliding velocity. The recycled alloy showed a lower friction coefficient and a lower wear rate when compared to the conventional alloy. A higher hardness and a relatively higher volume fraction of ß- phase with a denser distribution near to the surface were the reasons for the improved wear behaviour.

Key words

Magnesium alloy; High pressure die casting; Recycled alloy; Microstructure; Wear resistance;

The use of magnesium alloys in the automotive sector is increasing day by day owing to their excellent combination of properties [1].   The extensive employment of these alloys is likely to result in the increase of scrap levels, and in this context the recycling of magnesium alloys has become a topic of interest in recent times, as the energy required to produce recycled alloys is much lower compared to primary production of magnesium [2]. Even though there are concerns with regard to the impurity levels in the recycled alloys, there had been successful attempts to produce what is referred to as "secondary alloy" with acceptable properties [3-4]. The characterisation of mechanical properties and corrosion behaviour of conventional magnesium alloys have been addressed extensively by researchers, but there are only a few publications on the tribological behaviour of these alloys [5-9].   Further, there seems to be no published information available on the tribological characteristics and wear behaviour of recycled magnesium

alloys in the as-cast condition, and hence the current work aims at the understanding of the dry sliding wear of a recycled high pressure die cast AZC1231 magnesium alloy and at comparing the performance of this with that of a conventional AZ91 magnesium alloy.

The conventional AZ91D and recycled AZC1231 magnesium alloys were produced by high pressure die casting in a cold chamber machine using a melt temperature of 690°C and a pressure of 400 bar. The chemical compositions of the alloys are presented in **Table 1**. Metallographic specimens were prepared by polishing successively with 220, 320, 400, 800, 1200 and 2500 grit emery sheets followed by polishing in diamond slurry (1 μm). Finally, the specimens were polished in colloidal silica emulsion and etched in a solution comprising 3.5 g picric acid, 6.5 ml acetic acid, 20 ml water and 100 ml ethanol, and metallographic examinations were performed in a Leitz light optical microscope. Vickers hardness measurements were performed under a load of 50 N and the values reported are average of 5 reading.

The dry sliding wear behaviour of the AZ91D and AZC1231 alloys was assessed using a Tribotec ball-on-disc oscillating tribometer with an AISI 52100 steel ball of 6 mm diameter as static friction partner. Specimens of size 25 mm x 40 mm x 5 mm with a mean surface roughness (R_a) of 0.10 $\pm$ 0.02 μm were used for the studies. Dry sliding wear tests were performed, in duplicate, at ambient conditions (25 $\pm$ 2°C, 30 $\pm$ 2% RH), at three different load levels, viz. 2 N, 5 N and 10 N with an oscillating amplitude of 10 mm and at a sliding velocity of 5 mm s^{-1} over a sliding distance of 12 m. The worn out surfaces on the disc and on the ball were examined in a Cambridge Stereoscan 200 scanning electron microscope (SEM), and the wear depth measurements of the worn tracks were performed with a Hommel profilometer.

The optical micrographs of the AZ91D and AZC1231 magnesium alloys at a region close to the surface are given in **Figures 1(a)** and **(b)**, and the gradient in the

microstructural features from the surface to the interior regions are evident in the embedded micrographs. In terms of the phases, the AZ91D had a higher volume fraction of α-dendrites close to the surface when compared to that in the recycled alloy. In the recycled alloy, the higher volume fraction of ß-phase is apparently on account of the increased aluminium and zinc content. In addition to the ß-phase, the recycled alloy also contained τ-phase, which has been attributed to the higher amounts of copper and zinc in the alloy [3]. A closer examination of the microstructure at higher magnifications revealed that the network of ß-phase was denser in the recycled alloy than in its conventional alloy counterpart. The hardness of the conventional alloy was 83 ± 3 HV_5 and the recycled alloy registered a higher value of 105 ± 3 HV_5. The higher amounts of intermetallic phases and their finer distribution in the matrix were responsible for these increased hardness levels.

The friction coefficients as a function of sliding distance observed for the AZ91D and AZC1231 alloys in the ball-on-disc wear tests under 2 N load are depicted in **Figure 2**. The average friction coefficient values at this load were found to be 0.31 and 0.26 for the AZ91D and AZC1231 alloys, respectively. Optical macrographs of the worn tracks of the respective specimens and their wear depth profiles embedded in Figure 2 bring out the differences in the wear resistance of the two alloys. The wear track of the alloy AZ91D alloy was not only wider but also had a greater depth compared to AZC1231. The adhesive transfer of material from the magnesium substrate on to the ball was higher in the tests involving AZ91D, essentially due to the lower hardness causing higher degree of damage to the substrate.

In the tests under 5 N load, the average friction coefficient values of 0.29 and 0.25 for the AZ91D and AZC1231 alloys, respectively were marginally lower than those observed in the 2 N tests for both the alloys **(Figure 3)**. The wear track widths and depths were higher compared to those observed under 2 N in both specimens. With

increase in load to 10 N, still lower friction coefficient values were registered and the average friction coefficient values for the AZ91D and AZC1231 specimens were 0.27 and 0.23, respectively **(Figure 4)**. Chen et al., **[10]** observed a similar behaviour of decrease of friction coefficient with increase in load in ball-on-disc tests (with a 3 mm diameter steel ball) performed on AZ91D alloy. A recent work of An et.al., **[11]** with a pin-on-disc configuration (pin diameter : 6 mm), too, reported low friction coefficient values under higher loads. Even though the load levels reported were as high as 350 N in the cited investigation, the actual contact stress levels were lower than those experienced by the specimens in this investigation. However, neither of the above publications explained the causes for the lowering of friction coefficient with increasing load/stress levels. Based on the observations in this work, the drop in friction coefficent might be attributed to the increasing transfer of magnesium from the specimen to the ball with increasing load due to adhesive transfer mechanism, and the smearing of the HCP structured magnesium alloy on the surface of the steel ball is plausibly responsible for this phenomenon.

The normalised volume wear loss of the AZ91D and AZC1231 alloys under all these test conditions are depicted in **Figure 5**. It is evident that in both these alloy the normalised wear rate increased when the load increased from 2 N to 5 N, and with further increase in load to 10 N it was observed to come down. Chen et al., **[10]** have suggested three possible wear mechanisms as a function of load, viz. (a) oxidiative wear under loads below 2 N, (b) abrasive-micro machining between 2 N and 8 N, and (c) plasticity dominated delamination at loads greater than 8 N. In the current investigation, too, the wear of magnesium substrate under 2 N and 5 N loads seems to have been governed by the hardness differences between the steel ball (900 HV_5) and the soft magnesium substrate (<105 HV_5). In addition, the hard intermetallic phases removed from the magnesim alloy also could have contributed to wear process.

The examination of these two wear tracks in SEM at higher magnifications revealed the presence of deep scoring marks with accumulated wear debris in the grooves, suggesting the abrasive micro-machining mechanism under these test conditions. The wear tracks produced under 10 N load also had similar grooves; however, there were not many particles seen on the track, instead laminates were observed, with associated ridge formation at the edges of the track. It is probable that the wear process would have started as micro abrasion and due to the higher stress level, the wear mechanism might then have changed to plasticity dominated delamination. The normalised wear rate under 10 N load was lower than that observed in the case of the 5 N load tests, and it appears that the plastic deformation induced work hardening of the substrate could have been the reason for this.

In summary, the higher volume of intermetallics and the associated higher hardness in the recycled AZC1231 magnesium alloy provide a higher wear resistance when compared to that in the conventional AZ91D alloy under dry sliding conditions. In both the alloys, the wear mechanism appears to change from an abrasive micro-machining under 2 N and 5 N loads to plasticity dominated delamination at 10 N load. The reduction in the normalised wear rate at 10 N load might be attributed to the work hardening of the substrate. Further investigations to understand the wear behaviour/ mechanism of the recycled alloy under lubricated conditions and with surface modification are under way.

Acknowledgement

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Table

Table 1 Chemical composition of conventional and recycled AZ91 magnesium alloys
(All concentrations in weight %, balance Mg)

Alloy	Al	Zn	Mn	Si	Cu	Fe	Ni
Conventional	8.75	0.67	0.20	0.054	0.008	0.0022	0.00061
Recycled	11.70	3.04	0.48	0.39	0.47	0.0087	0.0032
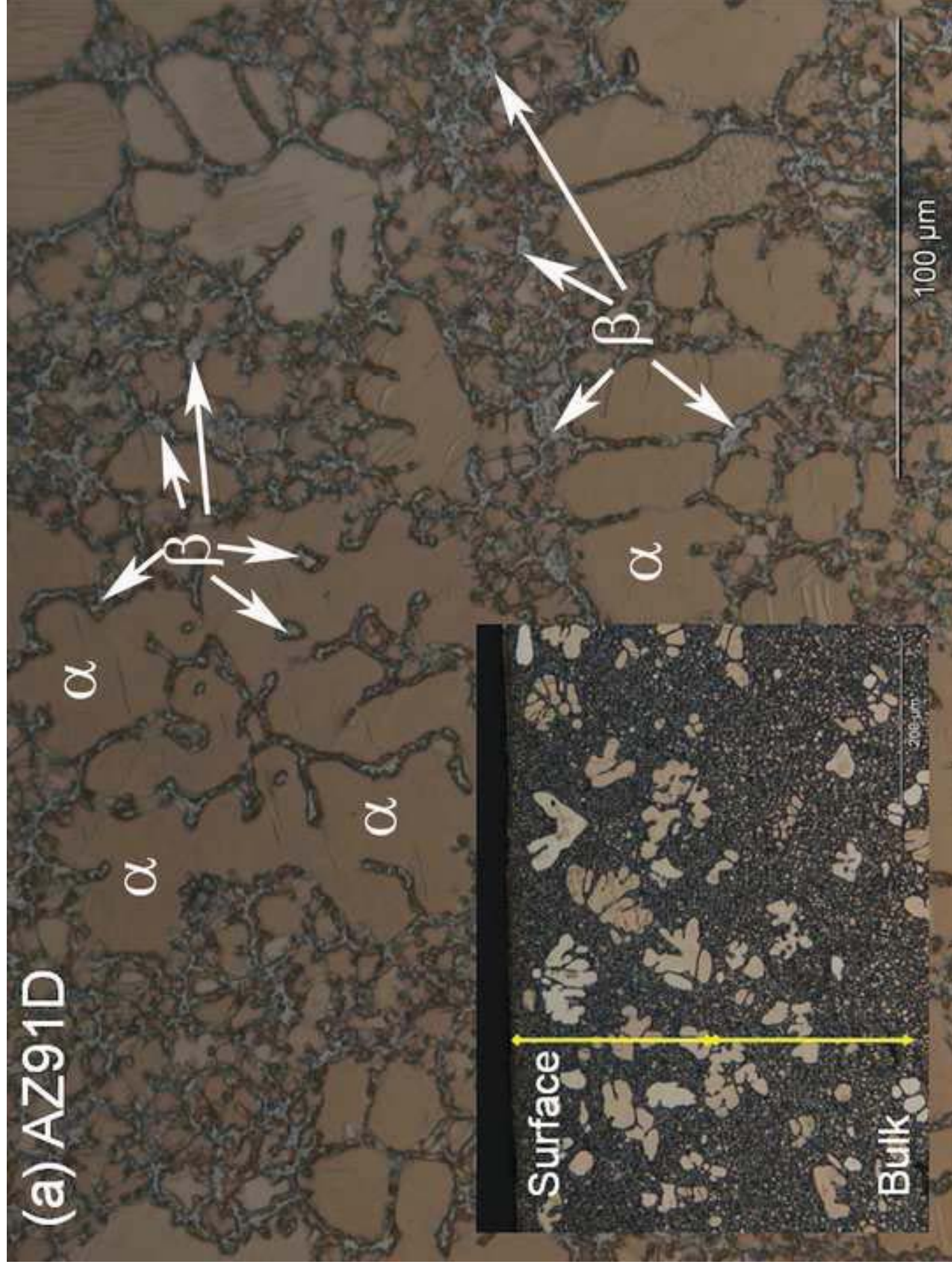
(a) AZ91D

(b) AZC1231
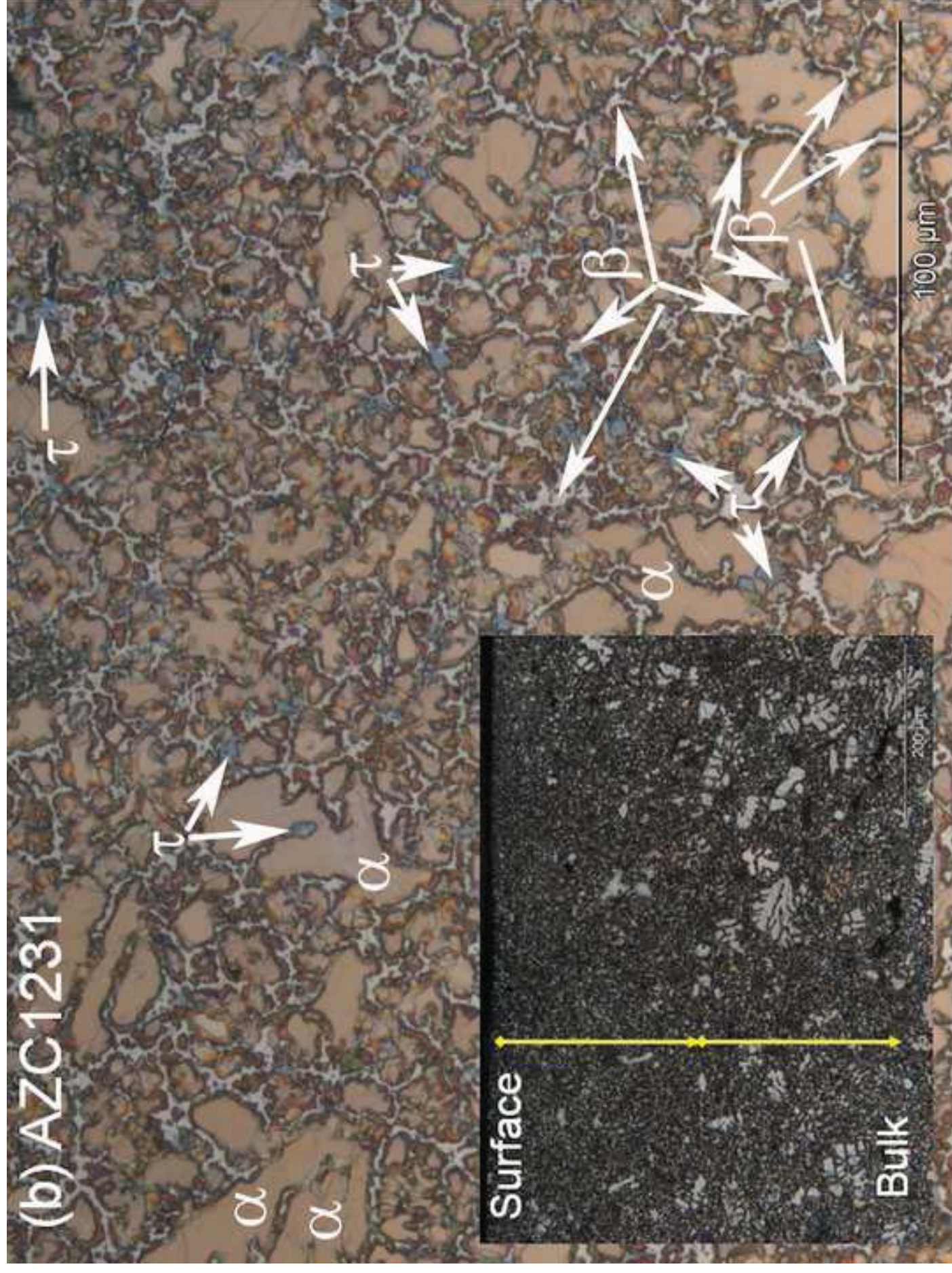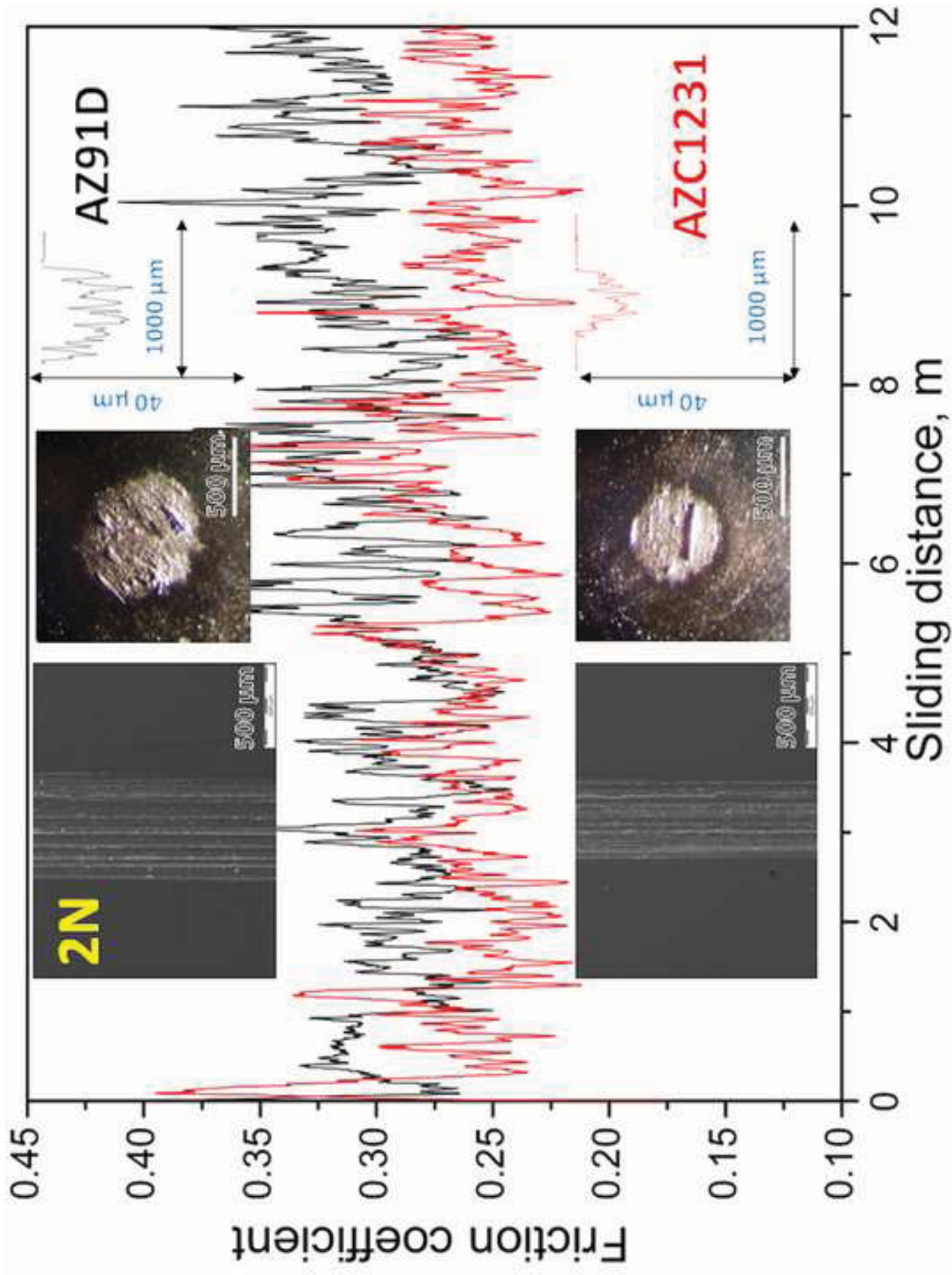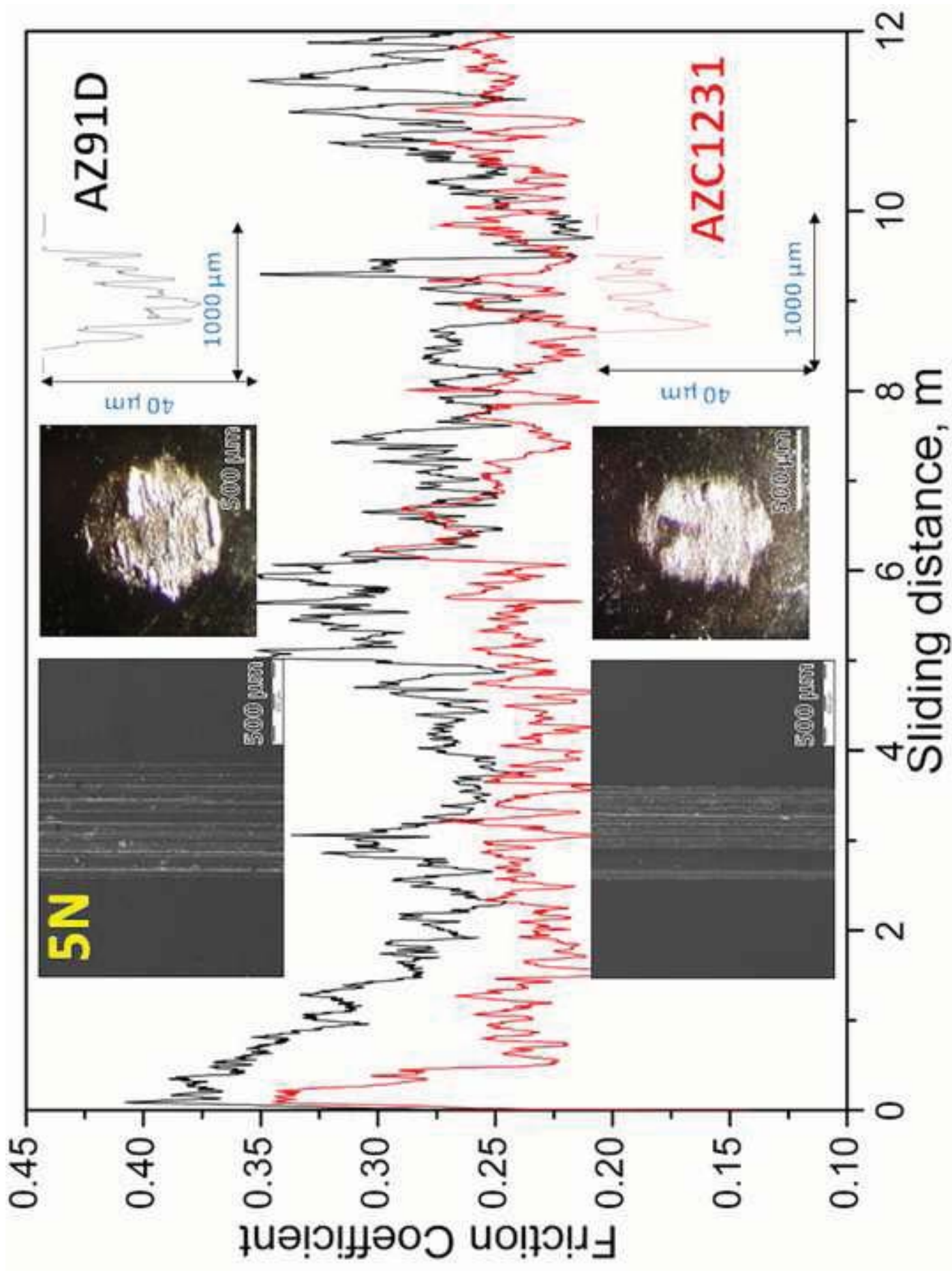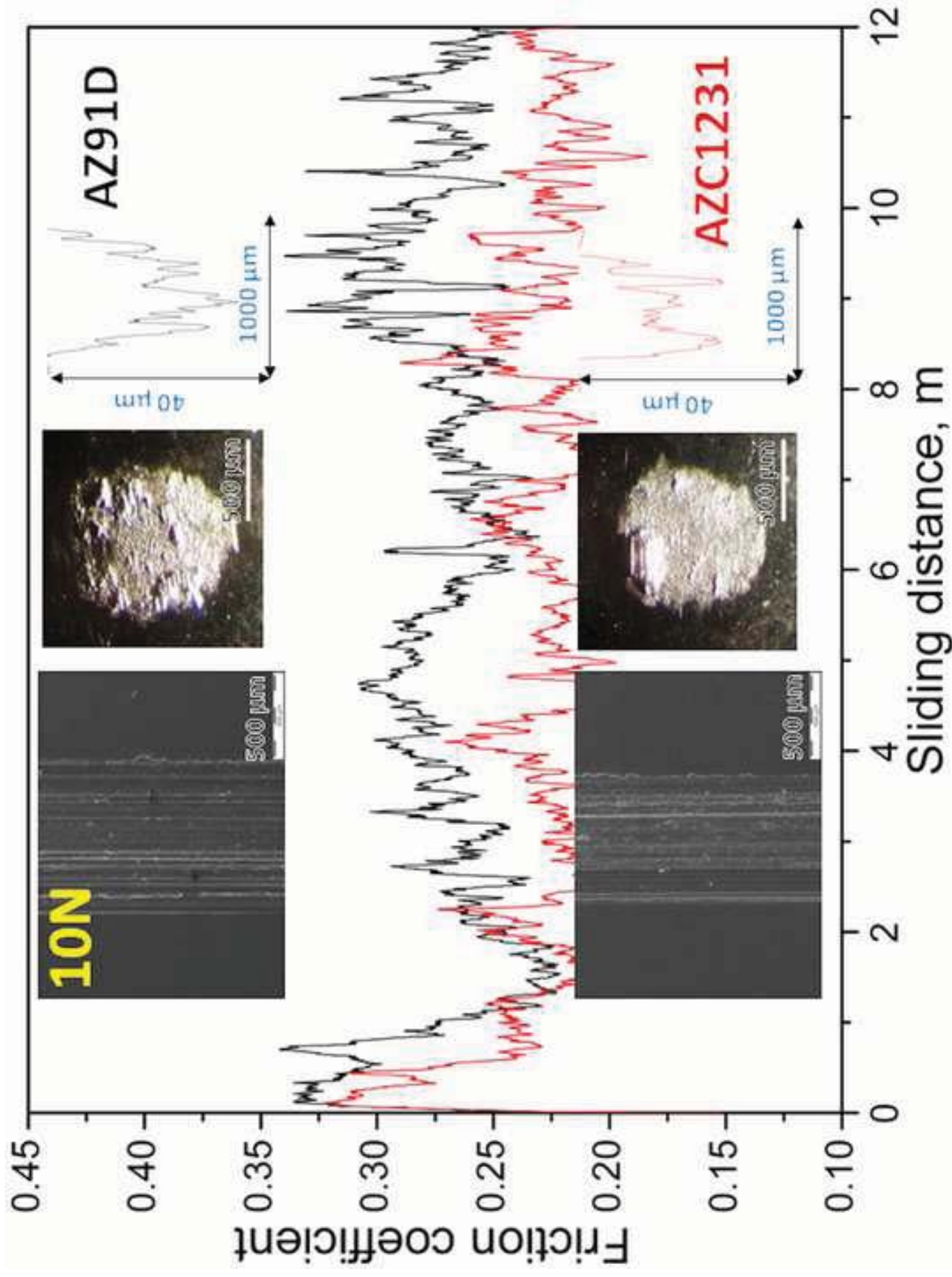
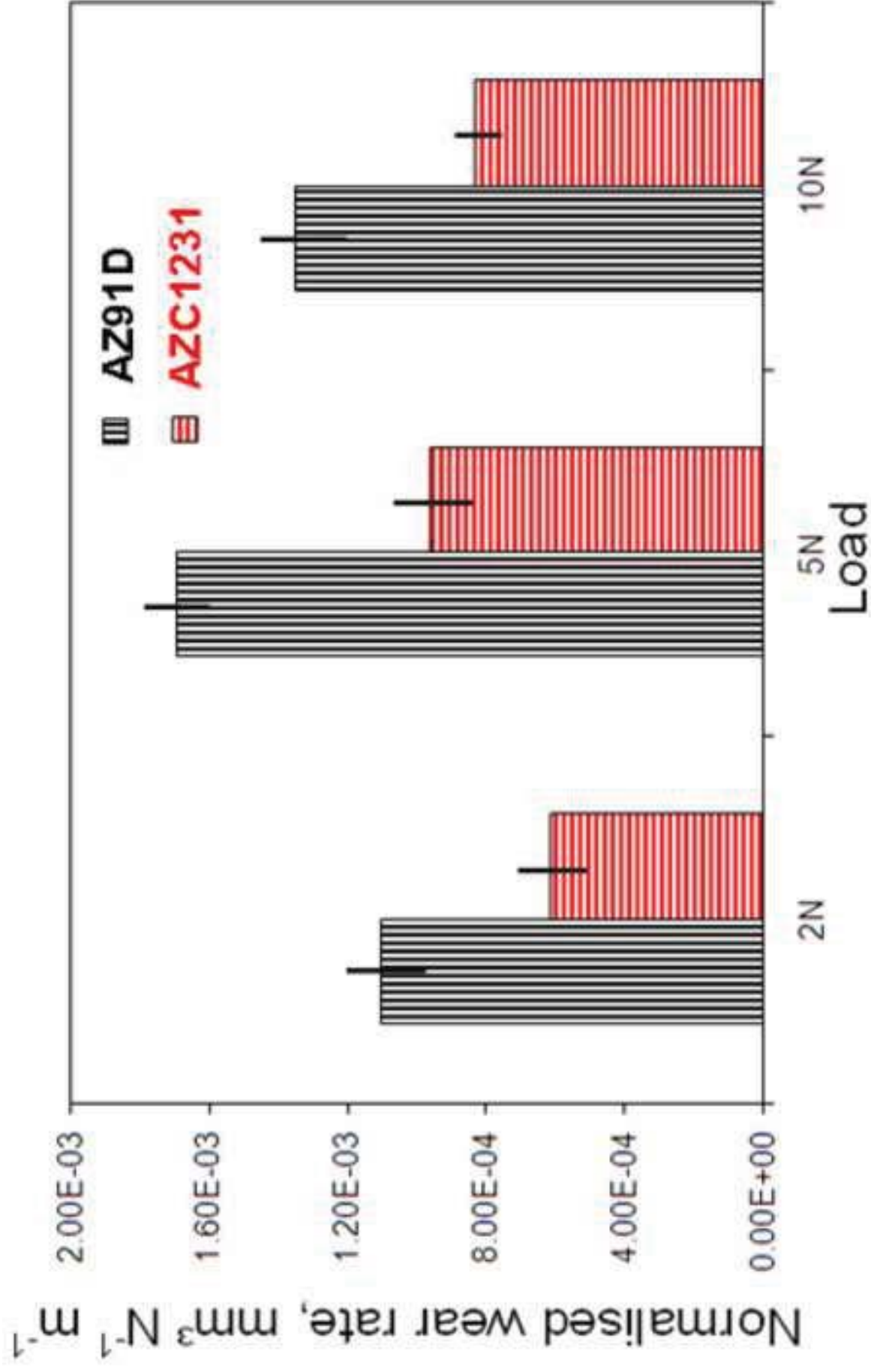Figure 3

Table Caption

Table 1 Chemical composition of conventional and recycled AZ91 magnesium alloys (All concentrations in weight %, balance Mg)

Figure Captions

Figure 1 Optical micrographs of the conventional (AZ91D) and recycled (AZC1231) magnesium alloys

Figure 2 Wear behaviour of AZ91D and AZC1231 magnesium alloys under 2 N load

Figure 3 Wear behaviour of AZ91D and AZC1231 magnesium alloys under 5 N load

Figure 4 Wear behaviour of AZ91D and AZC1231 magnesium alloys under 10 N load

Figure 5 Normalised wear rates of conventional and recycled AZ91 magnesium alloys