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Corrosive Wear Behavior of 2014 and 6061 Aluminum Alloy Composites

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Alloys of 2014 and 6061 aluminum reinforced with 0.1 volume fraction of alumina particles (VFAP) were subjected to impact scratching during a corrosive wear process. The transient currents generated due to the impact were measured in the two composites as well as in their respective monoliths. The effect of solutionizing time on the transient currents was correlated to the near surface microstructures, scratch morphology, concentration of quenched-in vacancies, and changes in grain sizes. It was observed that the transient current values increase with an increase in solutionizing time, indicating that the corrosive wear behavior is not strongly affected by the grain boundaries. However, a combination of pitting and the galvanic corrosion may account for the typical corrosive wear behavior exhibited by the alloys and the composites of this study.

Keywords alloy 2014, alloy 6061, composites (metal matrix), corrosion

1. Introduction

The corrosive wear behavior of alloys from an Fe-Ni-Cr ternary system was studied using a scratch technique (Ref 1-10). The scratch technique consisted of using the alloys in the form of a rotating cylindrical electrode and was impacted by a stylus containing a Vickers hardness indenter. The sample was immersed in an electrolyte, and the impact produced a scratch when the bare surface of the electrode in contact with the electrolyte gave rise to a transient current known as the depassivation. However, repassivation occurred immediately after the stylus left the surface of the electrode and the transient current values began to decrease. A study of the transient current response (TCR) from the Fe-Ni-Cr alloys indicated that the microstructural features contributed to the transient current significantly. It was shown that decreasing the grain size and increasing the dislocation density and volume fraction of mechanical and annealing twins increased the transient current values in the scratch tests.

The scratch technique was used (Ref 11) for 6061 aluminum alloy in the monolith form and reinforced with 0.10, 0.15, and 0.20 volume fractions of alumina particles (VFAP). The TCR observed in this nonferrous alloy system showed that increasing the grain size as a result of increasing the solutionizing time at 540 °C increased the transient current values, an observation opposite of that earlier observed in ferrous alloys. This behavior was attributed to the insensitivity of the grain boundaries to contribute significantly to the corrosion behavior of the nonferrous alloys. An empirical relationship among the transient current evolved, time of solutionizing, and VFAP was developed for the composites of 6061 aluminum alloys.

The purpose of this paper is to present the results of a study (Ref 11) to compare the corrosive wear behavior of the composites of type 6061 and 2014 aluminum alloys reinforced with 0.1 VFAP. The monoliths were used to determine the effect of reinforcements on the transient current generation in samples that were solutionized from 1 to 20 h at 540 °C. The microstructural characterization around and in the scratches was carried out using scanning electron microscopy (SEM) and transmission electron microscopy (TEM).

2. Experimental Details

The composites of 2014 and 6061 aluminum alloys reinforced with 0.1 VFAP were purchased from Duralcan, Inc. (San Diego, CA), which uses a proprietary casting process for fabrication. The rods were machined to prepare electrodes 12.7 mm in height with inner and outer diameters of 6.4 and 12.4 mm, respectively. The experimental setup was divided into three main units: electrochemical cell, potentiostat, and data acquisition system. The electrochemical cell was made out of Teflon (E.I. DuPont de Nemours & Co., Inc., Wilmington, DE), and 0.1 M NaCl solution was used as an electrolyte. The sample was held in the cell in the form of an electrode rotating at a speed of 1500 rpm with the help of an electric motor. Silver brushes at the electrodes were used to help minimize the noise level from the signal. A standard calomel electrode was used as a reference electrode, which was separated from the main cell with the help of a bridge containing a saturated K_2SO_4 solution to prevent the migration of chlorine ions to the cell. A platinum cage wound around the cell interior served as the counter electrode. Purified argon gas was bubbled through the electrolyte 1 h before the experiment and during the entire duration of the testing. A stylus containing Vickers hardness indenter at its tip was allowed to drop on to the rotating cylindrical electrode from a known height, and the force was recorded by a transducer. The transient current and load were both recorded on a MacIntosh computer (Apple Computers, Inc., Cupertino, CA) using the LABVIEW (National Instruments, Austin, TX) program.

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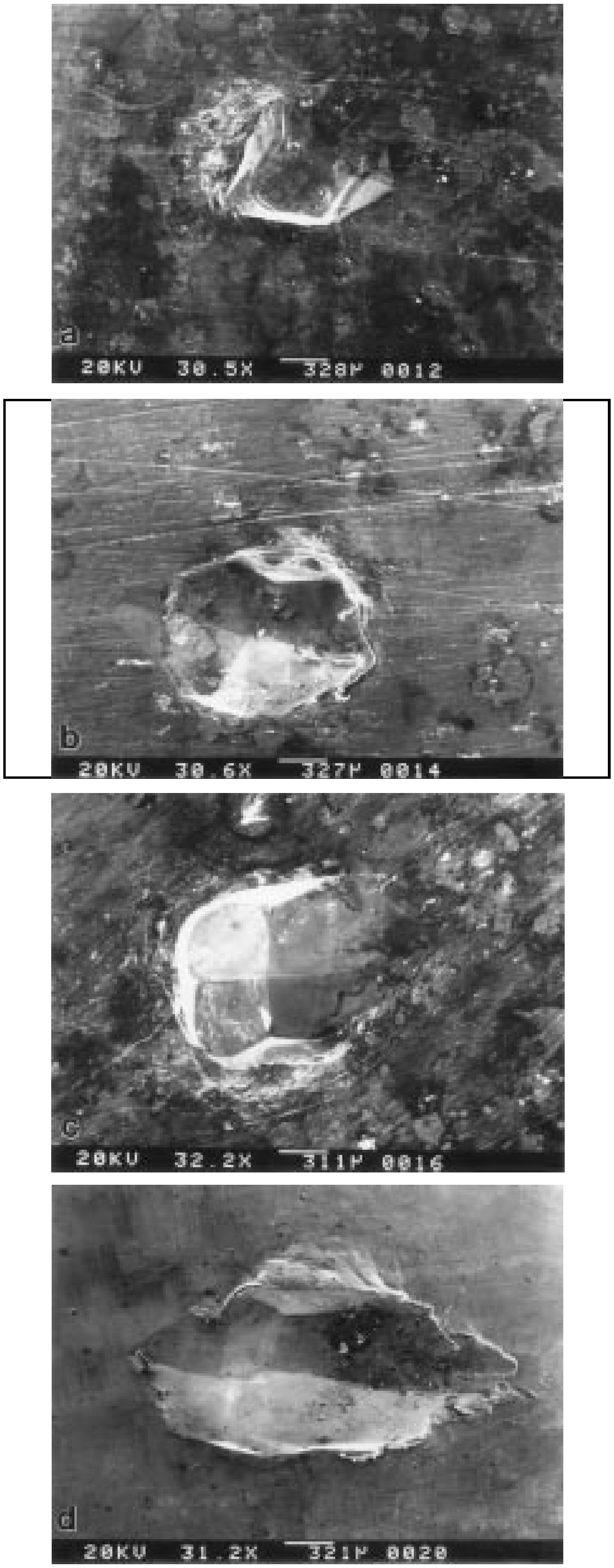

Fig. 1 Typical morphologies developed after impact scratching the electrodes of 6061 aluminum alloy, which have been solutionized at 540 °C for (a) as-received condition, (b) 5, (c) 10, and (d) 20 h

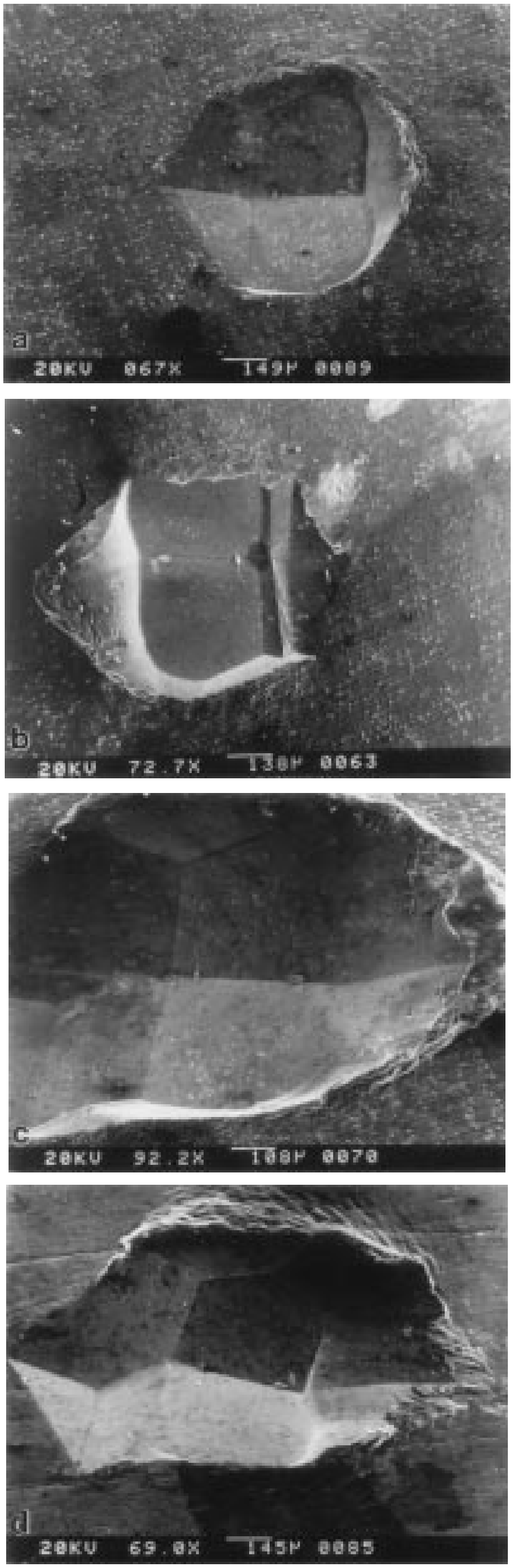

Fig. 2 Typical morphologies developed after impact scratching the electrodes of 6061 aluminum alloy reinforced with 0.1 VFAP, which have been solutionized at 540 °C for (a) as-received condition, (b) 5, (c) 10, and (d) 20 h

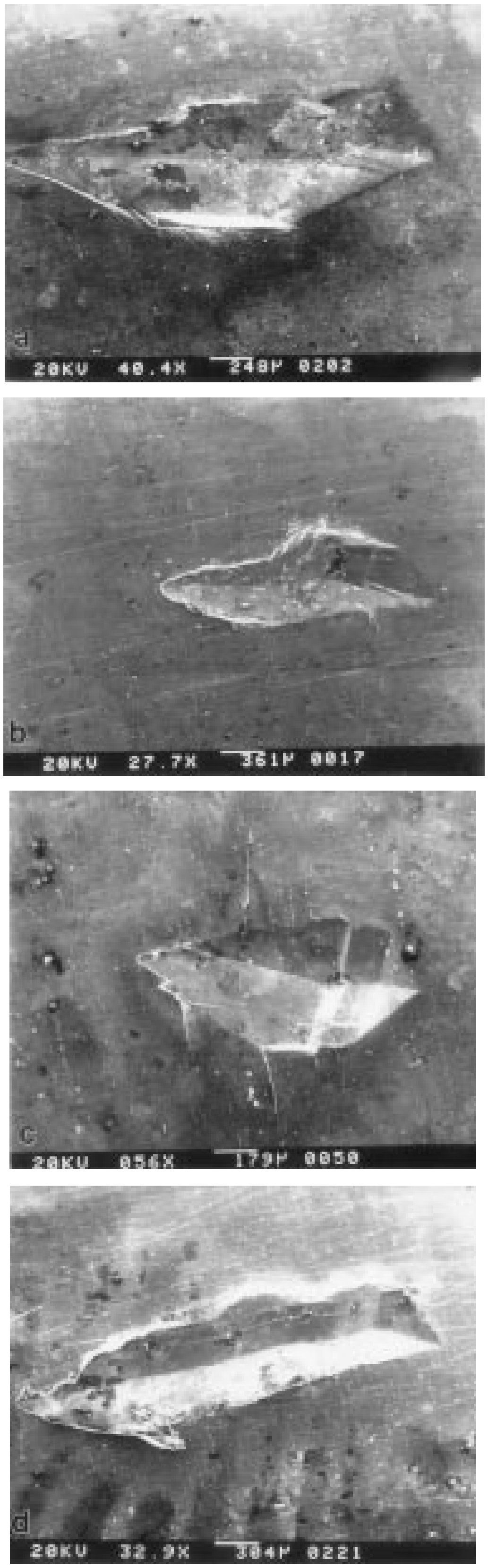

Fig. 3 Typical morphologies developed after impact scratching the electrodes of 2014 aluminum alloy, which have been solutionized at 540 °C for (a) as-received condition, (b) 5, (c) 10, and (d) 20 h

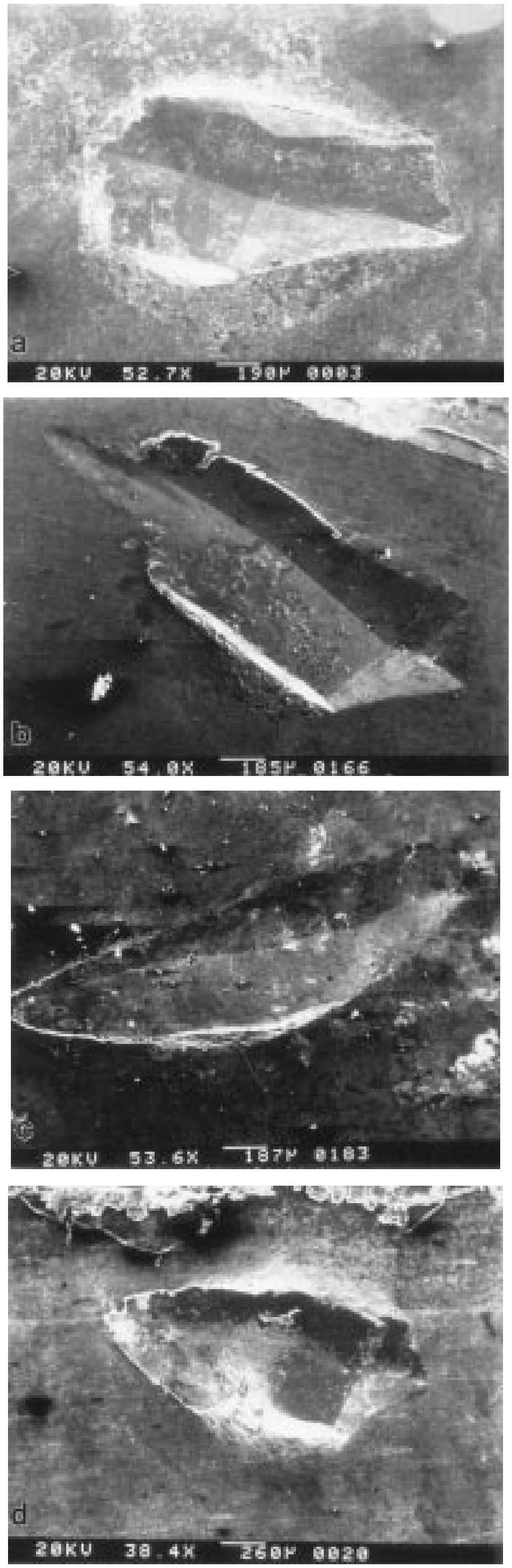

Fig. 4 Typical morphologies developed after impact scratching the electrodes of 2014 aluminum alloy reinforced with 0.1 VFAP, which have been solutionized at 540 °C for (a) as-received condition, (b) 5, (c) 10, and (d) 20 h

The samples were solutionized in air at 540 °C for 5, 10, 15, and 20 h and immediately quenched in water. They were lightly polished with 0.1 μm alumina powder on a polishing cloth prior to the scratching process. The heat treated samples were always stored in a refrigerator to avoid the natural aging of the samples.

3. Results and Discussion

3.1 Scratch Morphology

Figures 1 and 2 show the morphologies that were developed in 6061 aluminum alloy in monolith form and reinforced with 0.1 VFAP, respectively, when subjected to impact scratches in the electrolytic cell. The scratches are shown for the as-received condition and for samples that were solutionized for 5, 10, and 20 h at 540 °C. It can be readily seen that due to the larger grain size at longer solutionizing time, the area of the scratch increases. Almost identical behavior was observed for 2014 aluminum alloy in the monolithic form and reinforced with 0.1 VFAP, as shown in Fig. 3 and 4.

Another important observation to be noted from Fig. 1 to 4 is the presence of large amounts of pits in composites reinforced with 0.1 VFAP. The relative concentration of the pits is small for the monolith in both alloys. This may be due to the consequences of different mechanisms of corrosion occurring in the monoliths and the composites and is discussed in the "Conclusions."

3.2 Near Scratch Surface Microstructures

There are microstructural features associated with both the alloys and composites in the solution treated conditions as well as during the corrosive wear process that may be responsible for the observed behavior. The dislocation densities were observed to be much higher in the composites compared to the monoliths in the scratched conditions. This may be due to two different reasons. First, the scratching process resulted in the generation of dislocations through a simple plastic deformation. Second, it was shown that the presence of ceramic reinforcements in metal matrix introduced the coefficient of thermal expansion (CTE) differences when held at a high temperature. Thus when the composites were solutionized, the aluminum, being a lower melting point element, expanded more than the alumina particles, being of higher melting point, which resulted in the compressive stresses that were developed at the particle/matrix interface. Thus the dislocations were generated, known as CTE dislocations. Obviously the quenching of the samples from the solutionizing temperature in ice water preserved such CTE dislocation structure at room temperature. It must be noted that the dislocations can act as an anodic site for the corrosion to occur in the form of galvanic coupling.

3.3 Transient Current Response

Figures 5 and 6 show the magnitudes of transient currents developed during the impact scratching of the monoliths and the composites, respectively, as a function of solutionizing time. The curve fitting in these two figures did not include the points in the as-received (for zero solutionizing time) condition because they were not expected to follow mechanisms similar to solutionized samples. The increase in transient current values with an increase in solutionizing time can be seen in these figures for the three cases. It might first appear that the 6061 aluminum alloy reinforced with 0.1 VFAP shows a decrease in transient current values with an increase in solutionizing time. However, the authors feel that the overall differences in the magnitudes of the transient currents are so small in this case that an experimental scatter in the data may account for such

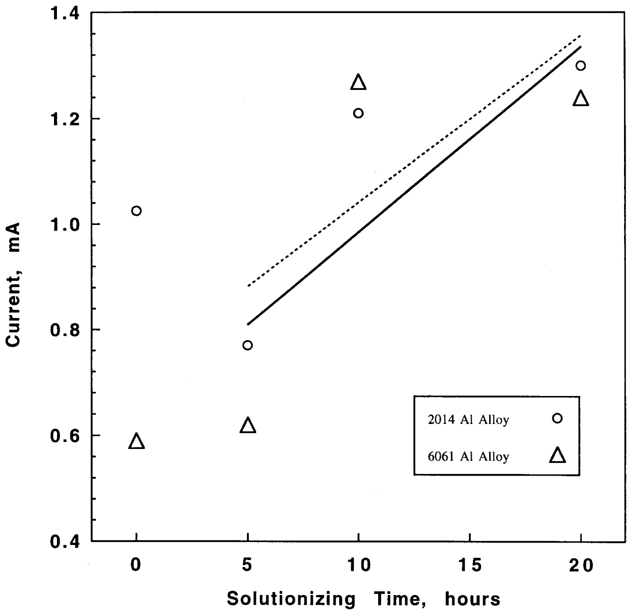

Fig. 5 Transient current values generated during impact scratching of 6061 and 2014 aluminum alloys in the monolithic form as a function of solutionizing time

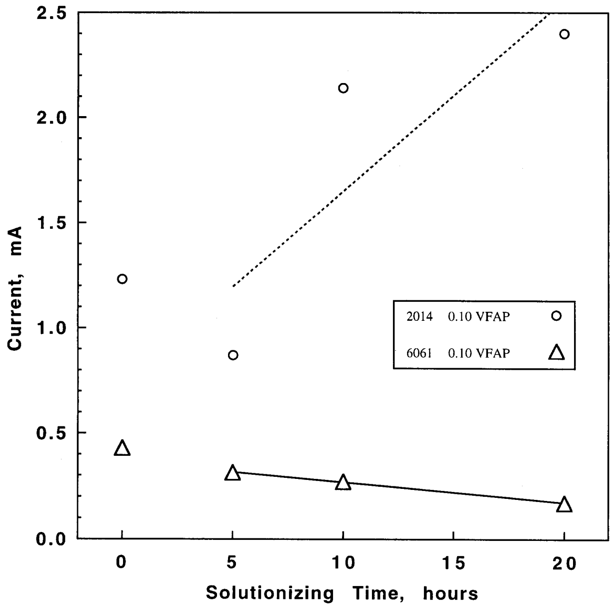

Fig. 6 Transient current values generated during impact scratching of 6061 and 2014 aluminum alloys reinforced with 0.1 VFAP in the monolithic form as a function of solutionizing time

behavior. In fact, it is assumed that this composite does not change transient current values as a result of changes in solutionizing time.

4. Conclusions

The grain boundaries are considered to be anodic sites in most corrosion phenomenon. Thus the grain growth occurring during solutionizing must result in reduction in total surface area of the grain boundaries. If the grain boundaries are playing an important role in the corrosive wear of the alloys and the composites of this study, then a decrease in transient current value with an increase in solutionizing time is to be expected, in direct contradiction with the experimental observations shown in Fig. 5 and 6. It may, however, be assumed that the grain boundary corrosion may not be a significant contributing factor in the generation of transient currents, and a dominating corrosion mechanism may involve the pitting corrosion compared to the galvanic corrosion where the grain boundaries act as the anodic sites. There is experimental evidence of the pitting corrosion occurring in the composites, as seen in Fig. 2 and 4. It must be noted that galvanic corrosion is not excluded, but the domination of pitting corrosion in composites is emphasized in this study.

The initiation of pits may be due to the retention of quenched-in vacancies from the solutionizing treatment. An increase in solutionizing time at 540 °C for both alloys and composites would alter the vacancy concentration gradient from the interior of the grain to the grain boundaries. The longer diffusion time would allow this concentration gradient to be increased, and the coalescence of the vacancies may be expected, resulting in the nucleation of a micropit at which the corrosion can occur. Further work is being carried out to prove the validity of such a hypothesis.

Thus the corrosive wear behavior observed in this study is a result of a weighted average of the contributions from the pitting and the galvanic corrosion. The exact fraction of the contributions from these two forms of corrosion cannot be determined according to the results of this study.

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