Microstructure and Wear Study of Al 7075-T6/Eggshell/SiC/Al_2O_3 Hybrid Composites

Girija Moona, Vikas Rastogi, R. S. Walia and Rina Sharma

Abstract In present experimental investigation, hybrid aluminium metal matrix composites were fabricated using stir casting technique by infusing eggshell particles (0.5, 1 wt%), SiC particles (1, 1.5 wt%) and Al_2O_3 particles (1.5, 2.5 wt%) into Al 7075-T6 metal matrix. The developed composites were further characterized for microstructures using FESEM, X-ray diffractometry and EDS techniques. Tribological behaviour investigations were carried out using a pin-on-disk tribometer for comparative study between as-cast Al 7075-T6 alloy and Al-7075-T6/Eggshell/SiC/Al_2O_3 composites. During dry sliding wear test at room temperature, there was a decrease of 33% in wear rate, 20% in coefficient of friction and 20% in frictional force of composites, whereas in presence of lubricant, the developed composites exhibited maximum reduction of 85% in wear rate, 46% in coefficient of friction and 46% in frictional force as compared to their unreinforced counterparts. Due to augmented tribological properties, fabricated hybrid composites can reasonably be used for lightweight wear-resistant applications.

Keywords Stir casting · Reinforcement · Hybrid composites · Microstructure · Tribology

1 Introduction

Main objective of developing composite materials is to make the matrix and perform combinations to produce the best possible material characteristics that cannot be achieved by conventional materials. Aluminium metal matrix composites (AMCs) offer a wide spectrum of advantages with enhanced mechanical and physical properties to prefer their selection for most of the advanced engineering applications. They have always been one of the most prominent research interests of many material

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science researchers due to their applications in avionics, automobiles and defence sectors. AMCs are developed to attain desired material properties with an intention to cater the needs of component manufacturers for different utilizations in scientific fields. Advantageous attributes of aluminium composites provide cost-effective alternatives, replacing many conventional materials for intrinsic engineering applications. In aluminium composites, various reinforcements are mixed with pure aluminium/aluminium alloys to produce a combination of enhanced properties as compared to the base metal. Properties of aluminium composites can be tailored by varying metal matrix, reinforcements and process parameters. Mixing of Al_2O_3 with aluminium alloy Al 356 through stir casting route resulted into increased hardness [1]. Al 7075 infused with B_4C particles produced a composite with better hardness and enhanced wear resistance [2]. Al 2014/TiC composites exhibited increased hardness and strength [3]. Al 6061/SiC composites processed through liquid metallurgy route have high tensile strength and improved wear resistance as compared to the unreinforced alloy [4]. Aluminium alloy AK 12 reinforced with fly ash and fabricated through squeeze casting acquires reduced porosity and improved corrosion resistance [5]. Mixing of 6 wt% of fly ash particles with LM 6 alloy to fabricated aluminium composites resulted into increased hardness and tensile strength [6]. It has been observed that aluminium matrices reinforced with single reinforcements exhibited certain improved characteristics, while other significant attributes were compromised, such as, in case of Al 6061/fly ash composites, tensile strength and hardness were increased, while there was a reduction in ductility. In process of surmounting this issue, fabrication of hybrid composites with reduced interfacial area and reduced meniscus penetration defect is being encouraged in order to adopt them as more dependable and extensible materials [7]. Al 6061-SiC/Graphite hybrid composites with different reinforcement weight fractions demonstrated increased tensile strength [8]. AA6082 + (Si_3N_4 + Gr) hybrid composite investigated for hardness and tensile strength showed reduced percentage elongation and increased hardness [9]. There are many methods for fabrication of aluminium composites such as stir casting, powder metallurgy, squeeze casting, liquid infiltration and plasma deposition, etc. [10, 11]. In present experiment, aluminium hybrid composites were synthesized by using Al 7075-T6 as metal matrix and eggshell, silicon carbide and aluminium oxide particles as reinforcements through liquid metallurgy route, particularly adopting stir casting technique. It was noticed that generally composites processed via powder metallurgy route exhibited better mechanical characteristics yet stir casting was preferred mostly due to its simplicity, cost effectiveness, ability to cause better wettability between reinforcements and aluminium melt and uniform infusion of filler particles into aluminium metal matrix [12]. Synthesized hybrid aluminium composites were characterized for microstructure and wear investigations.

2 Experimental Procedure

Base metal matrix used for this experiment was Al 7075-T6 alloy with chemical composition 89% Al, 6% Zn, 2% Mg, 1.2% Cu, 0.5% Fe, 0.3% Mn, 0.4% Si, 0.2% Cr and 0.2% Ti. Three reinforcements, eggshell particles (0.5 wt% and 1 wt%, average particle size ~60 μm), SiC particles (1 wt% and 1.5 wt%, average particle size ~65 μm) and Al_2O_3 particles (1.5 wt% and 2.5 wt%, average particle size ~90 μm) were infused in metal melt to prepare hybrid aluminium composites using stir casting techniques. Calculated amount of base metal was weighed and put into graphite crucible in an electric furnace for melting at 900 °C. Simultaneously, the weighed amounts of reinforcements were preheated in a muffle furnace to remove absorbed gases and moisture content, hence improving wettability. The molten metal was stirred at a speed of 150 rpm using mechanical stirrer of stir casting setup (Fig. 1), and preheated reinforcements were added to metal vortex. After infusion of reinforcements into metal matrix, the crucible was kept in an electromagnetic stirrer (Fig. 1) for uniform dispersion.

After appropriate stirring and ensuring decent mixing of filler particles into molten metal, the fabricated castings were allowed to solidify (Fig. 2).

The fabricated composites were investigated for microscopic studies and wear behaviour. For microstructure study, polished pallets of dimension 10 × 10 × 5 mm^3 (Fig. 3) were prepared, whereas for wear study, the specimens were prepared as per ASTM G 99-17 (Fig. 4) and tested on a pin-on-disk tribometer against a rotating disk of EN 31 steel.

Fig. 1 Stir casting setup for composite fabrication

Fig. 2 Composite castings

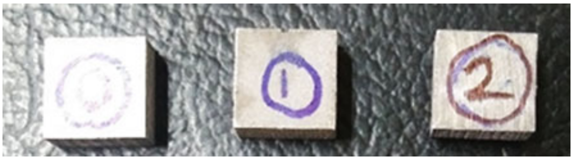

Fig. 3 Specimens for microstructure study

Fig. 4 Specimens for wear study

3 Results and Discussions

3.1 Microstructure Study

As-cast Al 7075-T6 sample (marked as 0) and two aluminium hybrid composites samples (marked as 1 and 2) with different reinforcement contents were conventionally polished and cleaned for optical imaging using Field Emission Scanning Electron Microscope, Make: Zeiss; Model: Supra 40VP. On microstructural analysis, no reinforcement was noticed in as-cast Al 7075-T6 specimen optical micrograph (Fig. 5), while the hybrid composite images (Figs. 6 and 7) indicated presence of

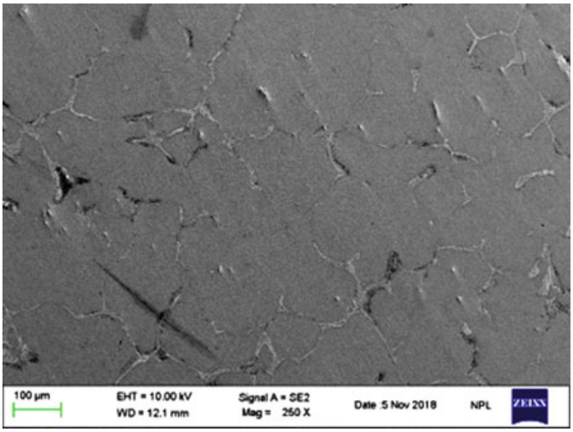

Fig. 5 Microstructure of as-cast Al 7075-T6

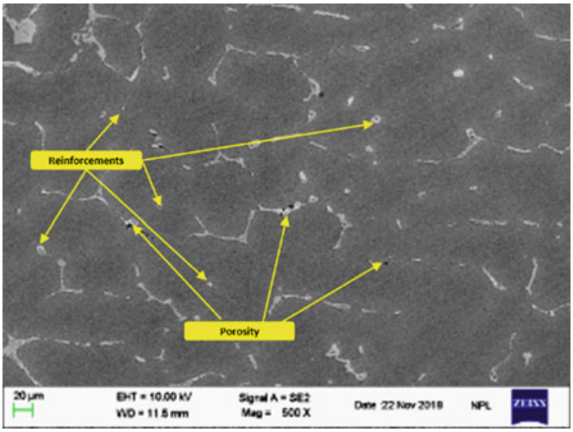

Fig. 6 Microstructure of Al 7075-T6/0.5 wt% eggshell/1.0 wt% SiC/1.5 wt% Al_2O_3 hybrid composite

reinforcement particles into Al 7075-T6 matrix. Some clusters of reinforcements due to agglomeration and porosity due to moisture on reinforcement particles surfaces and shrinkage during solidification were also observed.

The X-ray diffraction (XRD) analysis using X-Ray Diffractometer (Make: Rigaku Japan, Model—Miniflex-II) and Energy dispersive spectroscopy (EDS) using EFSEM (Make: Zeiss; Model: Supra 40VP) of as-cast Al 7075-T6 sample showed only aluminium alloy constituents peaks, ruling out the presence of any filler in base metal matrix (Fig. 8).

On conducting elemental analysis of hybrid aluminium composites using XRD and EDS, peaks of Si, Al and eggshell were visible in addition to Al 7075-T6 constituents peaks (Figs. 9 and 10). The oxygen and carbon contents in fabricated composites were found to be insignificant due to limited amount of reinforcements.

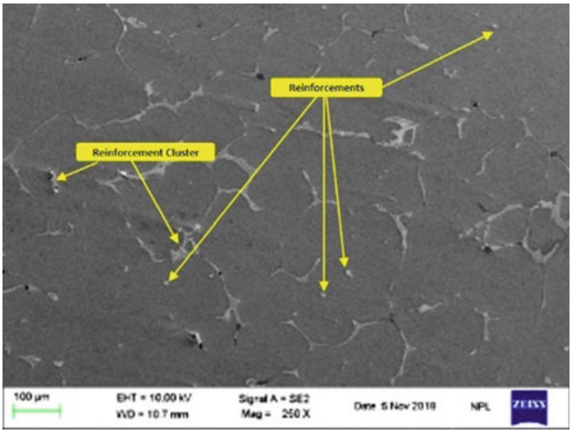

Fig. 7 Microstructure of Al 7075-T6/1 wt% eggshell/1.5 wt% SiC/2.5 wt% Al_2O_3 hybrid composite

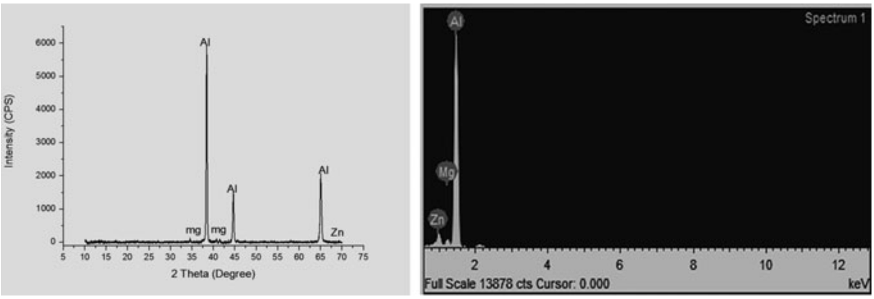

Fig. 8 XRD pattern and EDS profile of as-cast Al 7075-T6

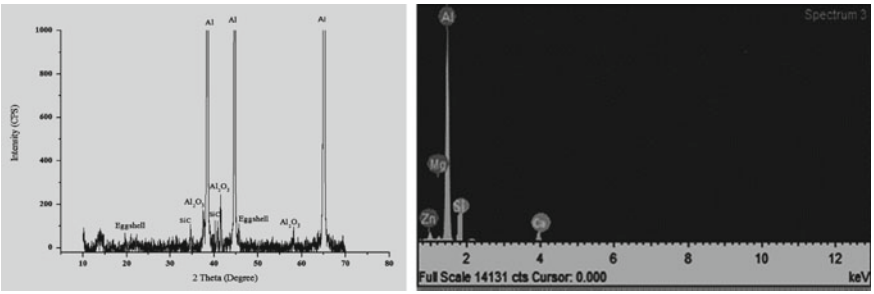

Fig. 9 XRD pattern and EDS profile of Al 7075-T6/0.5 wt% eggshell/1.0 wt% SiC/1.5 wt% Al_2O_3 hybrid composite

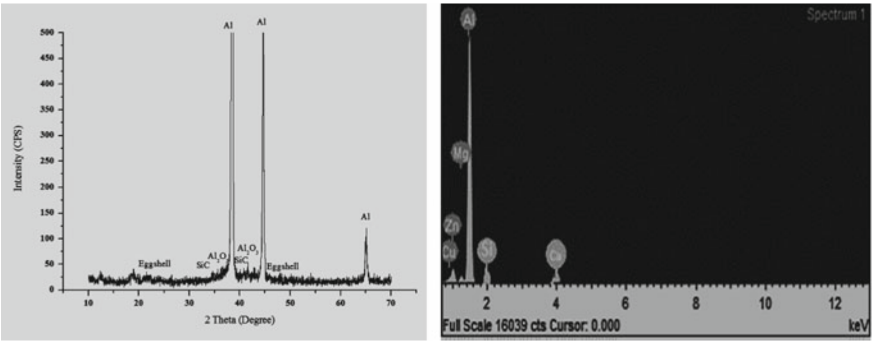

Fig. 10 XRD pattern and EDS profile of Al 7075-T6/1 wt% eggshell/1.5 wt% SiC/2.5 wt% Al_2O_3 hybrid composite

3.2 *Wear Behaviour*

Tribological behaviour of hybrid aluminium composites was investigated using a pin-on-disk rotary tribometer, Make: Atlas; TR-20L-PHM 800-DHM 850 (Fig. 11) by applying constant load of 20 N, for sliding distance of 2 km at a speed of 2 m/s at room temperature (32 °C) in accordance with dry sliding wear test conditions and in presence of lubricant for distinct wear-resistant applications.

Dry sliding wear tests were conducted at room temperature for as-cast Al 7075-T6 sample and hybrid aluminium composite samples. Graphs were plotted for wear rate, coefficient of friction and frictional force using experimental outcomes as shown in Fig. 12a–c.

During dry sliding wear tests at room temperature, as-cast Al 7075-T6 showed wear rate: 1.08 µm/s, average coefficient of friction: 0.121 and average frictional force: 2.247 N. Al 7075-T6/0.5 wt% eggshell/1.0 wt% SiC/1.5 wt% Al_2O_3 hybrid composite displayed wear rate: 0.797 µm/s, average coefficient of friction: 0.098 and average frictional force: 1.972 N, whereas Al 7075-T6/1 wt% eggshell/1.5 wt% SiC/2.5 wt% Al_2O_3 hybrid composite exhibited wear rate: 0.727 µm/s, average coefficient of friction: 0.096 and average frictional force: 1.938 N. Synthesized composites showed improved wear characteristics in terms of 33% reduced wear rate,

Fig. 11 High temperature pin-on-disk rotary tribometer for wear study

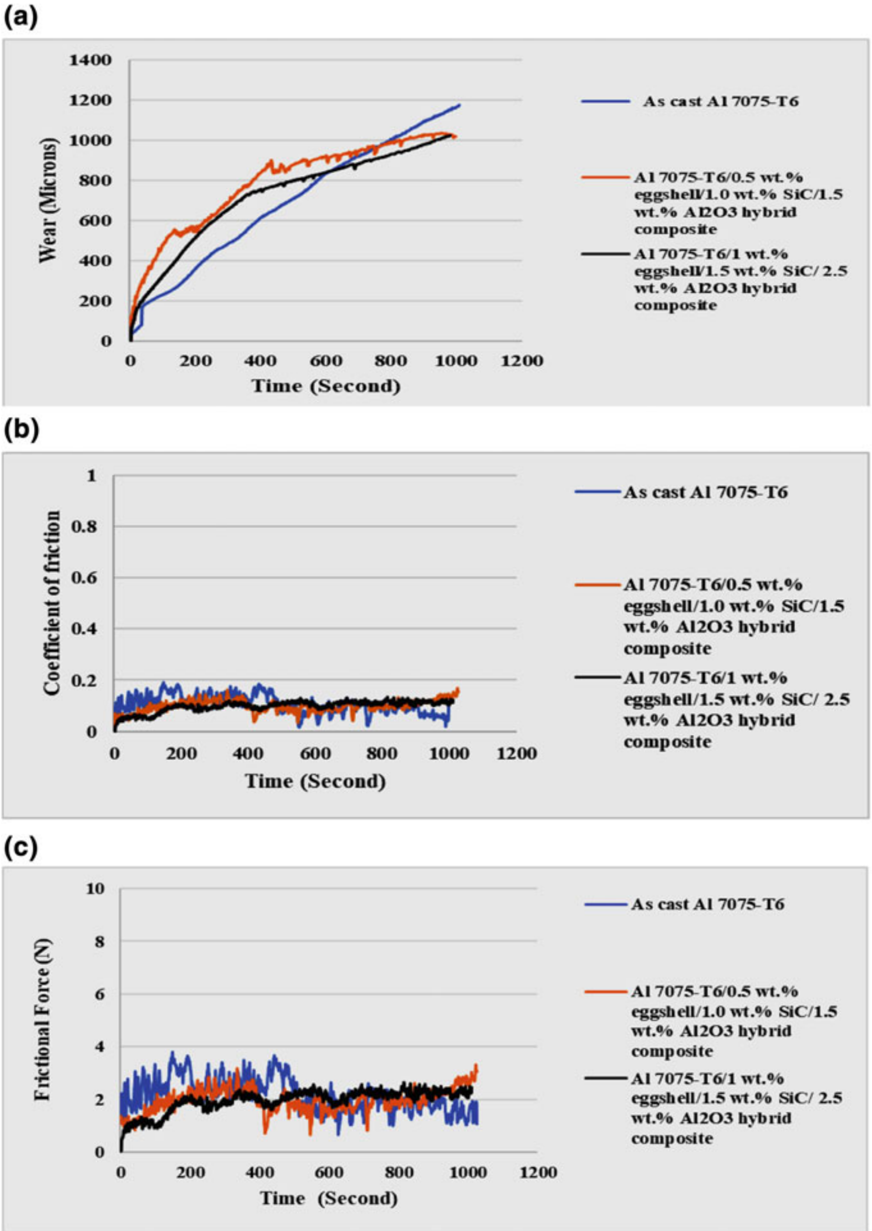

Fig. 12 **a** Wear versus time during dry sliding wear test. **b** Coefficient of friction versus time during dry sliding wear test. **c** Frictional force versus time during dry sliding wear test

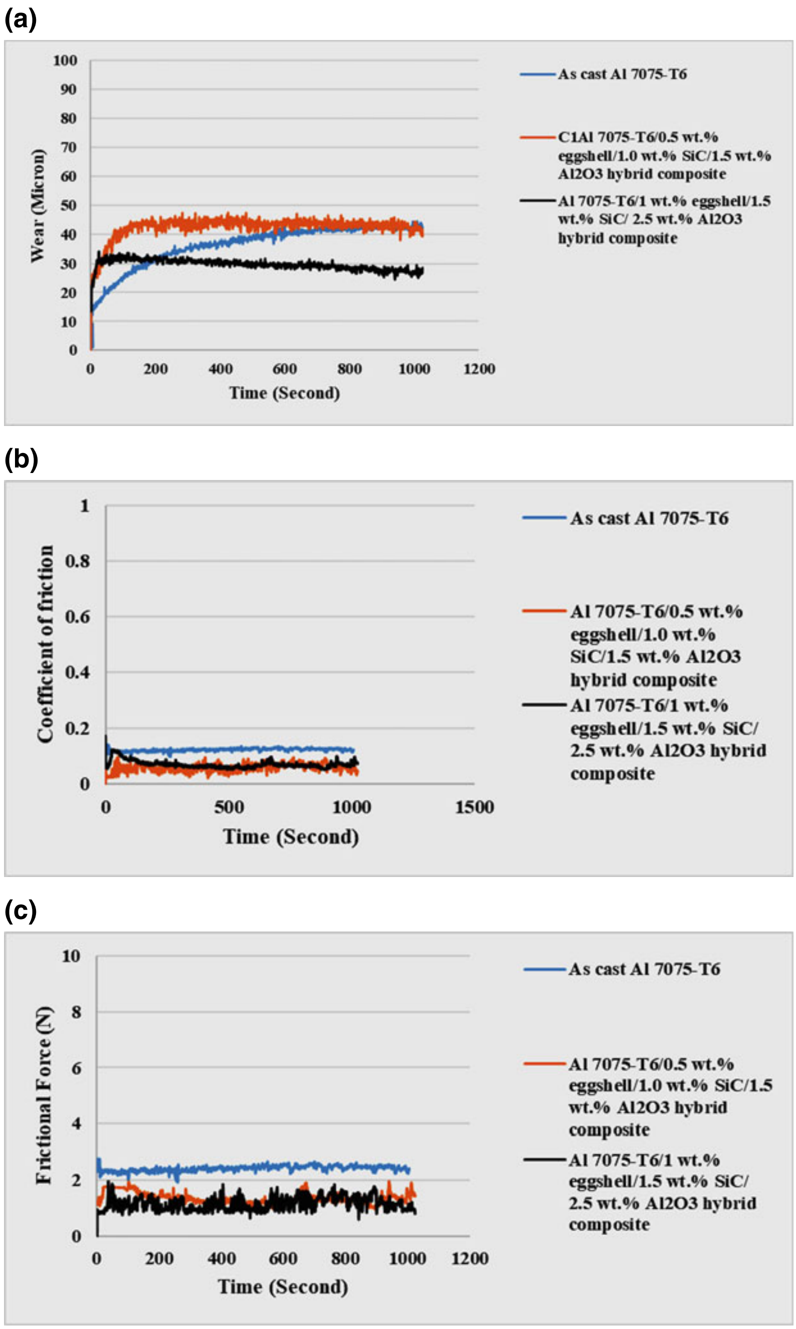

Fig. 13 **a** Wear versus time with lubrication. **b** Coefficient of friction versus time with lubrication. **c** Frictional force versus time with lubrication

20% reduced coefficient of friction and 20% reduced frictional force in comparison with as-cast Al 7075-T6 due to enhanced seizure resistance offered by reinforced particles. Additionally, wear properties were enhanced with filler content in hybrid composites.

Wear tests were also carried out in presence of a synthetic oil lubricant at room temperature. The developed composites exhibited phenomenal enhancement in tribological properties. Plots in Fig. 13 a, b and c exhibit wear properties of as-cast Al 7075-T6 sample and hybrid composites in aforesaid experimental conditions.

With lubrication, as-cast Al 7075-T6 offered wear rate: 0.022 μm/s, average coefficient of friction: 0.105 and average frictional force: 2.173 N. Al 7075-T6/0.5 wt% eggshell/1.0 wt% SiC/1.5 wt% Al_2O_3 hybrid composite demonstrated wear rate: 0.005 μm/s, average coefficient of friction: 0.070 and average frictional force: 1.340 N, whereas Al 7075-T6/1 wt% eggshell/1.5 wt% SiC/2.5 wt% Al_2O_3 composite showed wear rate: 0.003 μm/s, average coefficient of friction: 0.057 and average frictional force: 1.177 N.

The synthetic oil layer between specimen pin and rotating disk prevented direct contact of the two surfaces resulting into a maximum reduction of 85% in wear rate, 46% in coefficient of friction and 46% in frictional force as compared to the pure alloy metal casting.

4 Conclusion

In present investigation, hybrid aluminium metal matrix composites were prepared under specified experimental conditions using stir casting technique and characterized for elemental analysis and wear behaviour.

- Al 7075-T6/0.5 wt% eggshell/1.0 wt% SiC/1.5 wt% Al_2O_3 and Al 7075-T6/1 wt% eggshell/1.5 wt% SiC/2.5 wt% Al_2O_3 hybrid composites were fabricated successfully.
- Optical micrographs of synthesized composites exhibited uniform distribution of reinforcements into metal matrix, indicating their stable microstructure.
- EDS and XRD analysis of as-cast Al 7075-T6 and developed hybrid composites showed peaks of alloy constituents and reinforcements infused into metal matrix for fabrication of composites.
- During dry sliding wear test, there was a maximum decrease of 33% in wear rate, 20% in coefficient of friction and 20% in frictional force of composites in comparison with as-cast Al 7075-T6 alloy.
- Wear tests were also conducted in the presence of a synthetic oil lubricant. Synthesized composites exhibited a maximum reduction of 85% in wear rate, 46% in coefficient of friction and 46% in frictional force as compared to their unreinforced counterparts.

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