SELF LUBRICATING EFFECT OF WET TRIBOLOGICAL BEHAVIOUR OF Al-Si/SiC MMCs

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Abstract
Silicon carbide (SiC) particles reinforced metal matrix composites (MMCs) were produced by a combined two steps process; vortex and subsequent squeeze casting. The tribological behaviour of the resultant composites was tested by a pin-on-disk method to determine the wear loss and friction coefficient against a counterface steel disk which its surface hardened to 50—55 Rc. The wear tests were conducted at 20 ^{o}C in water. The wear experiments were carried out with varying sliding speeds and loads. It was noted that increasing the size of SiC leads not only to alter the hardness of the Al-Si matrix but also shifts wear mechanisms. Decreasing the size of SiC introduced into Al-Si alloy resulted in decreasing friction coefficient but increasing wear loss. It was summarized that the wear test carried out at wet media showed that Al-Si-SiC composites are good candidate for load bearing applications at high humidity conditions.

1. Introduction
Incorporation of hard ceramic particles has been found to improve the wear resistance of aluminium to a great extent. Aluminium metal matrix composites (Al-MMC) reinforced by ceramic particles are therefore beginning to find commercial applications as wear resistant/friction materials in automobile, aircraft and other applications where the low density of Al-MMC is of great benefit. Considerable amount of research has been carried out on the tribology of Al-MMC [1-3].

Studies on the tribological properties of Al-Si alloys and A1 alloy matrix composites are active [4-6], because the demands for reduction in weight of machines are increasing. In the auto-motive industry, fiber-reinforced composites, having advantages of reduced weight and wear resistance, are now used for the pistons, piston rings, and cylinder liners of engines in Japan [7,8]. However, the fiber-reinforced composites have often a deleterious effect on the mating material by the abrasive action of the fractured fibers [8].

A number of production techniques have been proposed for discontinuously reinforced MMCs. In general, the particle mixing technique by creating a vortex in the liquid matrix is one of the easiest and cheapest production techniques. For eliminating particle and matrix interaction spray forming and osprey process has been used [9]. Both processes resulted to obtain high wear resistance against wear of the aluminium alloys. In this regard, Deuis et al. [10] have recently reviewed the present understanding of the wear mechanism of MMCs. It has been shown that the materials possessing high wear resistance under dry sliding conditions are associated with the stable tribolayer on the wearing surface and the formation of equiaxed wear debris [10]. The formation and removal of the tribolayer or the Mechanically Mixed Layer (MML) during wear depends on various factors such as sliding velocity, applied load, and nature of the atmospheric condition.

The objective of this study is to investigate in greater detail the wet wear behaviour of the Al-Si alloy reinforced SiC particle composites in contact with a bearing steel in wet conditions. Unidirectional sliding wear experiments were conducted as a function of particle size at a constant particle volume of 20 vol. % using a pin-on-disk type friction and wear apparatus. It is suggested to get the benefit from the self-lubricating effect in the water media to extend application of SiC particle reinforced composites.

2 Materials and testing methods

In the present work, an Al-Si alloy was used as matrix material. Silicon carbide (SiC) particles reinforced metal matrix composites (MMCs) were produced by a combined two steps process; vortex and subsequent squeeze casting. In the first step, 20 vol. % SiC particles and three different size (220, 320 and 400 mesh) of particles were mixed by vortex method under a protective gas environment of argon. The mixing of the particles into melt aluminium alloy was started at high temperatures, and mixing was continued until the matrix alloy reached to mushy state zone. The mixing was continued at least 5 minutes in the semisolid region for increasing the mechanical locking between reinforcements and matrix. The mixed composites were heated at high temperature and poured into a heated steel mould. In the second step, the solidification was completed under a squeezing pressure 50 MPa.

Al-Si alloy and SiC reinforced Al-Si alloys prepared by using standard metallographic techniques, and microstructure have investigated by light microscope. The matrix microhardness measurements were conducted in the composite matrices on polished samples using a 50 g load for 10 seconds.

The tribological behaviour of the resulting composites was tested by a wet pin-on-disk method to determine the wear loss and friction coefficient against a counterface steel disk which its surface hardened to 50—55 Rc. The wear tests were conducted at 20 ^{o}C temperature and in laboratory air conditions in water. The wear experiments were carried out with 0.25 m/s sliding speeds and under 3.0 N load. Weight loss was measured for composite pin samples, and volume changes were measured for counterface disk materials, and the wear rates were calculated using the standard formula. A complete wear microstructural characterisation on worn surfaces was conducted via SEM and EDS (JEOL 6060LV).

3. Results and Discussion

3.1. Microstructures

Fig. 1 (a)-(d) shows the microstructures of the Al-Si/20 vol. % SiC composites produced by introducing different size of SiC. In Fig. 1 (a)-(d), the optical microstructures are presented to show the SiC particles distribution in the composites. The microstructures show that all the composites produced by vortex and squeeze casting exhibited a uniform distribution of particles throughout the matrix. Additionally, no significant porosity can be seen, even in the 400 mesh SiC particle reinforced composites.

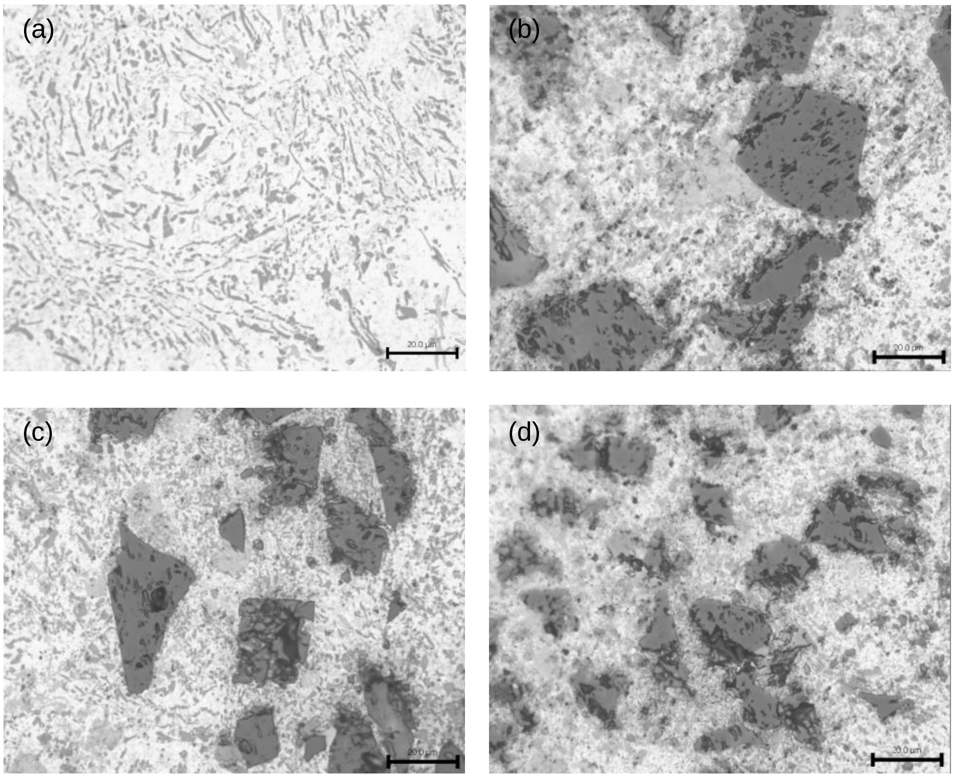

Figure 1. Optical micrographs of the (a) Al-Si alloy, (b) 280, (c) 320, (d) 400 mesh 20 vol. % SiC reinforced composites;

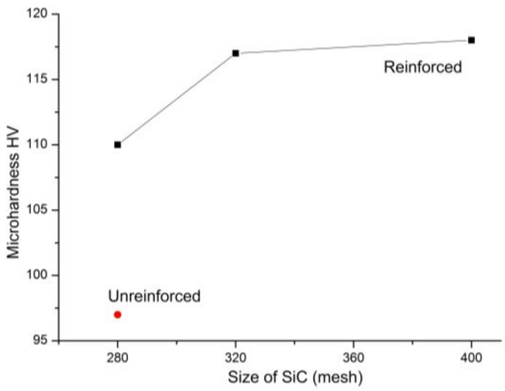

Figure 2. Matrix microhardness Al-Si alloy and variation of composite microhardness values depending on the particle size of SiC.

The microhardness measurement results are shown in Fig. 2. Microhardness tests confirmed that the hardness of the composite matrix increased with decreasing size of SiC particles. This is because the ceramic particles have different roles to increase the hardness of the metallic matrix. First, decreasing particle size can cause to increase load transfer from the matrix to the reinforcing phases. Second, decreasing particle size can decrease interparticle spacing and this result to prevent less dislocation sliding. Third, because of the thermal expansion coefficient mismatch between aluminium matrix and SiC particles, decreasing the grain size result in more disloaciton density around SiC particles and therefore, increasing strengthening.

3.2. Wear of Hybrid Composites

The wet wear pin-on-disk experiments showed that the size of SiC has a crucial effect on the tribological properties of the composites. Decreasing the size of SiC showed a dramatic decrease in the friction coefficient but a continuous increase in the wear loss. The dependence of the friction coefficient and the wear loss on the size of SiC is shown in Fig. 3 (a)-(b). In the unreinforced Al-Si alloys sample, a friction coefficient of 0.53 is measured but decreased continuously as the size of SiC decreased (as shown in Fig. 3 (a)). The composite, reinforced with 280 mesh 20 vol. % SiC produced a friction coefficient of 0.38 and decreasing the grain size as introducing 400 mesh SiC particle into the matrix leads the friction coefficient decrease to 0.28. It is suggested that this decrease in the friction coefficient was caused by increasing surface area of SiC. In recent years, it is studied that SiC particles in the high humidity media and/or in wet conditions such as in water result in observing low friction coefficient. In the wet sliding conditions the surfaces of the SiC particles produce silicon hydrates because of combined effect of friction temperature and water media. Therefore, decreasing the grain size causes increasing the SiC surface area in the matrix and lower friction coefficient [11]. In spite of macro porosity free microstructures has obtained in the present work, decreasing grain size resulted in increasing wear loss both in composite pin samples and counterface steel disk. This is because and also well-known scientific finding that increasing the second phase particle size produced better load bearing materials [11]. The increase in the wear loss and wear volume in our materials studied is shown in Fig. 3 (b).

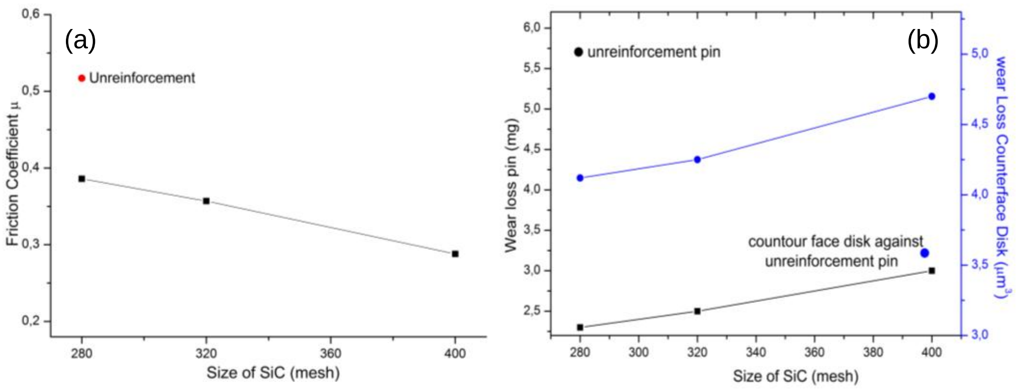

Figure 3. The effect of the size of SiC on (a) variation of the friction coefficient and (b) variation of the amount of wear loss pin and counterface disk.

The friction coefficient graphs that obtained simultaneously during pin-on disk tests are presented in Fig. 4 for the unreinforced alloy, and the composite reinforced with 400 mesh SiC particles. When the graphs are compared, it can be seen that the unreinforced alloy shows a higher friction coefficient than that of the composite reinforced with of 20 vol. % 400 mesh SiC particle (Fig. 4b). Unreinforced alloy also shows a large hysteresis and noisy in the friction force curve, which attributed to adhesion between the pin sample and counterface steel disk. However, although there are small fluctuations in the composite friction force curve, the hysteresis and the stability is better than unreinforced alloy. This is believed to be caused by lubrication effect of SiC particles in the water media. Decreasing friction coefficient in the Fig 4b refers to formation of lubricating species and the increase probably shows reversibility of lubricant phase formation.

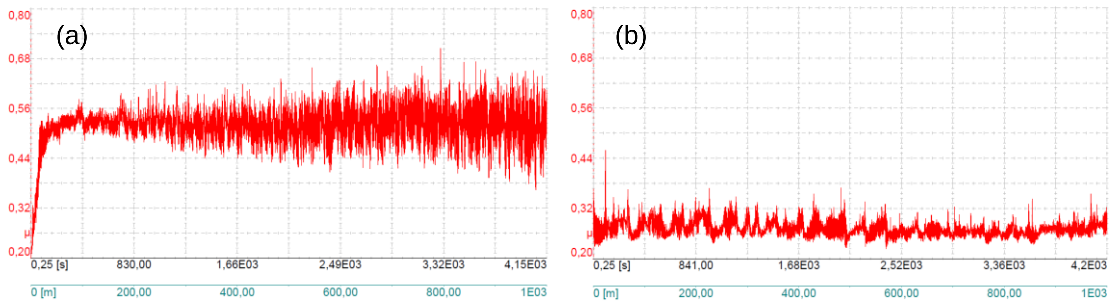

Figure 4. Friction coefficient variations with sliding distance of the (a)Al-Si alloy (b)400 mesh 20 vol. % SiC reinforced composites

3.3. Worn Surfaces

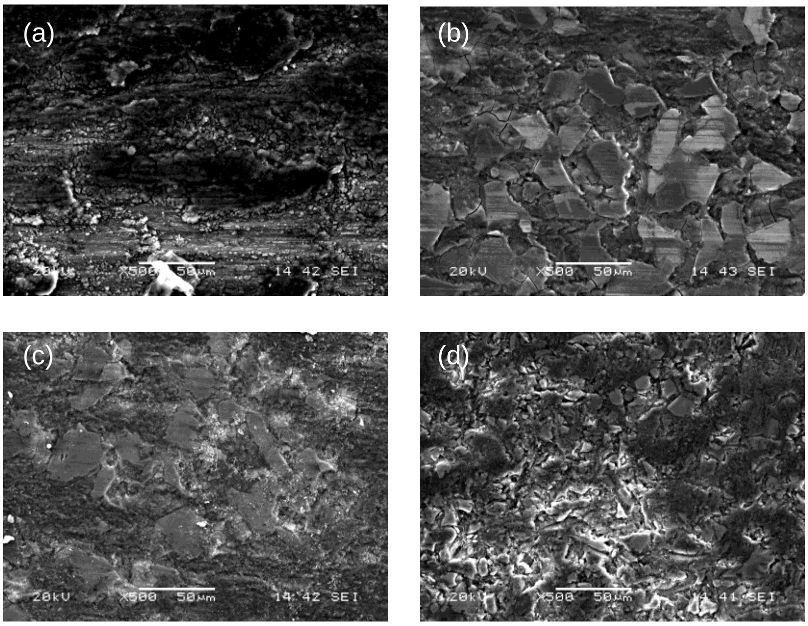

Figure 5 Low magnification worn surface micrographs of the composites (a) Al-Si alloy., (b) 280, (c) 320, (d) 400 mesh SiC reinforcement composite

Typical low-magnification SEM micrographs of the worn surfaces of the composites are illustrated in Fig. 5. Severe plastic deformation can be clearly seen on the worn surface of the Al-Si alloy surface (Fig. 5 (a)). The depth of the wear grooves is observed to change with irregular geometries in the composites. It can be seen clearly that the worn surfaces of the composites reinforced with 220 mesh 320 mesh SiC exhibit very small grooves parallel to the sliding direction (Fig. 5 (b) and (c)). These composite surfaces are also contained SiC particles that protruded on the worn surface. This is great evidence that the particles in size of 280 and 320 mesh can behave as an excellent load bearing second phase and the interfacial bond between the matrix, and the particles is sufficient for load bearing applications. The worn surface of the composite reinforced with 400 mesh SiC is relatively rough. The wear seems to be severe in comparison with the composite reinforced with 280 and 320 mesh SiC particles (Fig. 5 (d)). This can be emanated from possible poor interfacial bond or particle detachment because of deformation strengthening around the small sized SiC particles. Our observation during the test has already shown that the wear debris in this composite was finer in comparison with other samples to be studied.

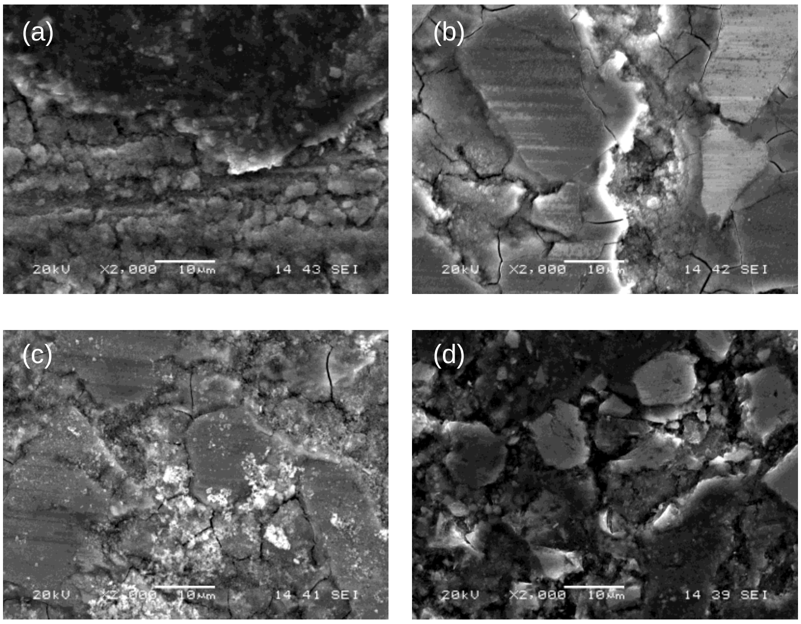

Figure 6 High magnification worn surface micrographs of the composites (a) Al-Si alloy., (b) 280, (c) 320, (d) 400 mesh SiC reinforcement composites

The worn surfaces of the alloys and composites were investigated at a high magnification. As shown in Fig. 6, materials from the surface were partially lifted and sheared off in the wear process (Fig. 6 (a), (d)). Plastic deformation can be found, and a severe abrasive wear appeared on the worn surfaces of the Al-Si alloy. The Al-Si alloy exhibited severe loss of the material (as shown in Fig. 6 (a)) by adhesion-induced tribo fracture. Introducing the SiC particles results SiC particles act as load-bearing elements and restrict the subsurface damage during sliding, and the particles also suppress the spelling process of tribo-layers from the surface [12]. The composite produced with 20 vol. % SiC and 220 mesh additions showed the smallest wear, as seen in Fig. 7 (b). However, the worn surface of the Al-Si and 400 mesh SiC composite exhibited higher surface damage than that of the composite Al-Si and 320 mesh SiC (Fig. 6 (d)).

During the friction process, shear instability occurred in some of the regions, resulting in an accelerated increase of shear displacement followed by turbulent plastic deformation in the subsurface region. It is believed the composites have high straining capability, and therefore, the worn surfaces of the studied composites did not show wear due to delamination. The large amount of plastic deformation caused an easy fracture in massive materials when adhesion took place in the Al-Si matrix composites.

For the Al-Si alloy and Al-Si/SiC composite, the worn surface was comparatively rough. Material transfer could be observed on the composite surfaces (Fig. 7), because the Fe element (indicated by EDS) was detected. As can be seen from the X-ray dot-map analysis the amount of Fe increases on the worn composite surfaces which contained 280 and 320 mesh sized particles. Decreasing the frail size to 400 mesh decreased the Fe transferring from the counterface steel disk to the composite surface as shown in Fig 7. This in a well agreement with the wear loss since in this particle size the composite pin becomes to exhibits higher wear loss. This probably implies that there is mechanically mixed layer (MML) on the composite pin surfaces. Another feature from the dot-map analysis can be seen that SiC particles protruded on the worn surfaces leading load bearing.

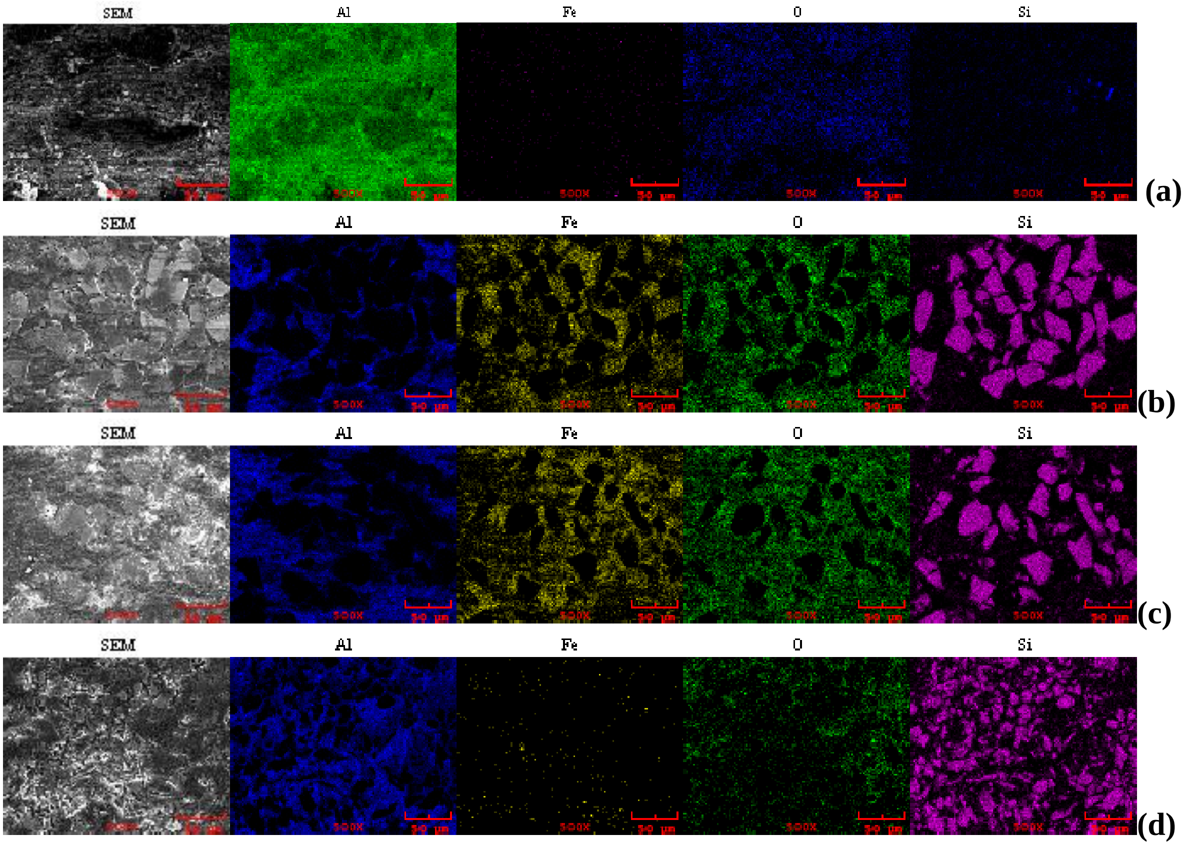

Figure 7 High magnification worn surface micrographs and X-ray dot-map of the composites (a) Al-Si alloy., (b) 280, (c) 320, (d) 400 mesh SiC reinforcement composite

4. Conclusion

Wear and friction studies of Al-Si alloy and three different size 20 vol. % SiC reinforced particles provided beneficial information when the test carried out in wet sliding media. The results, which lay a foundation for further examinations, are as follows:

1. Al-Si and Al-Si matrix composites reinforced with 20 wt. % SiC and three different sizes of SiC particles were successfully produced by a combined vortex and squeeze casting technique, which is a practical and low-cost technique for producing Al-Si based metal matrix composites.

2. The microhardness of the Al-Si matrix increased as the size of SiC decreased.

3. With the decreased size of to the Al-Si alloy 20 vol. % SiC composites, the friction coefficient was significantly decreased whereas wear loss increased.

4. Introducing SiC particle in 20 vol. % resulted in the wear mechanism transition from adhesive to abrasive predominant wear mechanisms.

5. Decreasing particle size of the Al-Si/20 vol. % SiC particle reinforced composites resulted in effective lubrication because of formation silicon hydrate lubricant on the SiC particle surfaces.

6. Introducing SiC particles into Al-Si alloy matrix showed that these composites can be successfully used in the high humidity and wet environment for load bearing applications.

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