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REVIEW ARTICLE

# Dry sliding friction and wear behavior of Aluminum/Beryl composites

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## ABSTRACT

In the present investigation, Al6061–beryl composites containing four different weight percentages (2, 6, 10 and 15%) of beryl have been fabricated using a vertex method (stir casting method). A pin-on-disc wear testing machine was used to carry out the dry sliding wear tests on both composites and matrix alloy over a load range of 5-15N and sliding velocity of 1.66m/s for various sliding distances of 1-6km. The uniform distribution of beryl particles was observed in the microstructural investigation of developed composites, which are more wear resistance than that of the matrix alloy. Scanning microscope analysis of wear surface supported the wear behaviour of both the matrix alloy the composites. Further, it was observed from the experimentation that the specific wear rate and average coefficient of friction decreased linearly with increasing weight fraction of beryl for the former while the latter with increasing normal load and weight fraction of beryl. The best results of minimum wear have been obtained at 10% weight fraction of beryl (size of particles:53-75µm).

**Key Words:** Metal Matrix Composites, Beryl, Wear, Friction, Microstructure.

## 1. Introduction

Aluminum metal matrix composites (AMMCs) are finding extensive commercial applications in various sectors such as space, automobile and structural industries, due to their high strength, high stiffness, and better wear resistance, particularly when component weight reduction is the key objective (Howell G.J, et.al.,(1995), Rawal S,et.al., (2001)). An excellent review on the dry sliding wear of discontinuously reinforced aluminum composites published reports about the principal tribological parameters that control the friction and wear performance of discontinuously reinforced aluminum composites (Sannino A.P,et.al., (1995)). Besides, this review also reports in detail about the mechanical and physical factors like effect of load, sliding velocity, sliding distance and material factors like reinforcement type, size, shape, and its volume fraction have been reviewed in detail. Increasing attention has been directed toward particulate MMCs for tribological applications due to the advantages of aluminum MMCs such as good sliding wear resistance, high load carrying capacity, and light weight. Extensive studies on the tribological characteristics of aluminum MMCs containing various reinforcements such as silicon carbide, alumina, short steel fiber, and fly ash are available in the literature (Surappa M.K., et.al., (2008), Alpas A.T, et.al.,(1992), Ylmaz O, et.al., (2001), Surappa, M.K,et.al.,(2007), Mandal D, et.al.,.(2007)). The above investigations have revealed that improvement in the dry sliding and abrasive wear resistance for aluminum alloy can be obtained by increasing the addition of particulate or fiber reinforcements. However, production cost of particulate reinforced composites is less compared to that of the fiber reinforced ones, owing to the lower costs of particles such as beryl, which is abundantly available. In addition, the mechanical and physical properties of particle composites are generally isotropic including those of Al-beryl composites (K. R. Suresh, et.al, (2002), K.G., et.al.,(2002)). Furthermore, cast metal matrix particulate composites represent the lowest cost composites, and these have been found in most of the tribological applications. However, there is no report on the dry sliding wear and friction properties of Al alloys containing beryl particles. Keeping all the above factors and very little published work on Al-beryl composites, this study presents results on the dry sliding friction and wear behavior of Al6061-beryl composites for different volume fractions of beryl particles and as a function of different applied loads with constant sliding velocity.

## 2. Experimental details

### 2.1 Materials

Beryl particles, which is naturally occurring mineral and having the formula ($Be_3Al_2(SiO_3)_6$) was used as the reinforcing agent, while Al6061 alloy has been used as the matrix. The beryl particles used were of 53-75μm size. These particles having hexagonal structure exhibited (K. R. Suresh, et.al.,(2002)) hardness of 7.5 to 8.5 on Mho's scale and density of 2.6-2.8g/mm$^3$, which is almost similar to that of Al6061. Table 1(a & b) shows the chemical composition of the matrix alloy (Al6061) and the reinforcement (beryl particles) respectively.

**Table 1(a):** Chemical compositions of Al6061 alloy (wt. %)

| Element | Mg | Si | Fe | Cu | Ti | Cr | Zn | Mn | Be | V | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Wt. % | 0.92 | 0.76 | 0.28 | 0.22 | 0.1 | 0.07 | 0.06 | 0.04 | 0.003 | 0.01 | Balance |

**Table 1(b):** Chemical composition of beryl (wt.%)

| Element | $SiO_2$ | $Al_2O_3$ | BeO | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | MnO |
|---|---|---|---|---|---|---|---|---|---|
| Wt. % | 65.4 | 17.9 | 12.3 | 0.8 | 1.34 | 0.48 | 0.55 | 0.004 | 0.05 |

### 2.2 Methods

#### 2.2.1 Preparation of composites

For the preparation of the composite, liquid metallurgy route was adopted as described in earlier works including the authors' work (K. R. Suresh, et.al., (2002), K.G. Satyanarayana, et.al.,(2002), H.N.Reddappa, et.al.,(2010)). Briefly, Al6061 alloy was first melted in graphite coated crucible, and then degassed. Vortex was created using a ceramic-coated steel impeller for about 10 minutes with a stirring speed of 400rpm.Preheated beryl particles were then introduced into this vortex, which was maintained at 720°C. The beryl particles of 2%, 6%, 10% and 15% was separately added and stirring was continued. Then, molten composite slurry is poured into coated cylindrical steel molds. Using these cast Al6061-beryl composites specimens for wear test were prepared by machining the cylindrical bar castings.

### 2.2.2 Sliding wear tests

Sliding wear tests were conducted in pin-on-disc wear testing apparatus (model: TR20-LE, Wear and Friction Monitor, Ducom Make, Bangalore, India) under varying load of 5-15N at a fixed sliding speed of 1.66m/s against EN32 steel disc of hardness 500HV. The pin samples were Φ8mm and 25mm in length. The surfaces of the pin sample and the steel disc were ground using emery paper prior to each test. In ordered to ensure effective contact of fresh surface with the steel disc, the fresh samples were subjected to sliding on emery paper of 240grit size fixed on the steel disc. During sliding, the load is applied on the specimen through cantilever mechanism and the specimens brought in intimate contact with the rotating disc at a track radius of 114mm. The wear losses of sample pins were measured as height loss in microns, which was recorded using an LVDT transducer of accuracy of 1μm. The measurement of wear loss of the pin was used to evaluate the volumetric loss.

### 2.2.3 Microstructure of aluminium alloy and composites

Microstructural studies of Al6061 alloy and beryl particles reinforced composites in as cast conditions with samples of dimensions Φ20mm and 10mm thick were done. The specimens were mechanically polished using standard metallographic practices and etched with Kellor's reagent prior to their microstructural examination by optical and scanning electron microscopy. The worn surfaces and subsurface regions after sliding wear tests were also examined by scanning electron microscope.

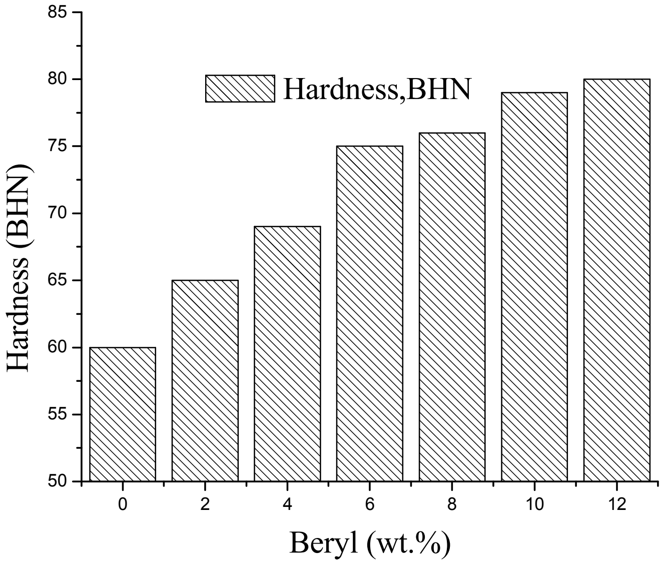
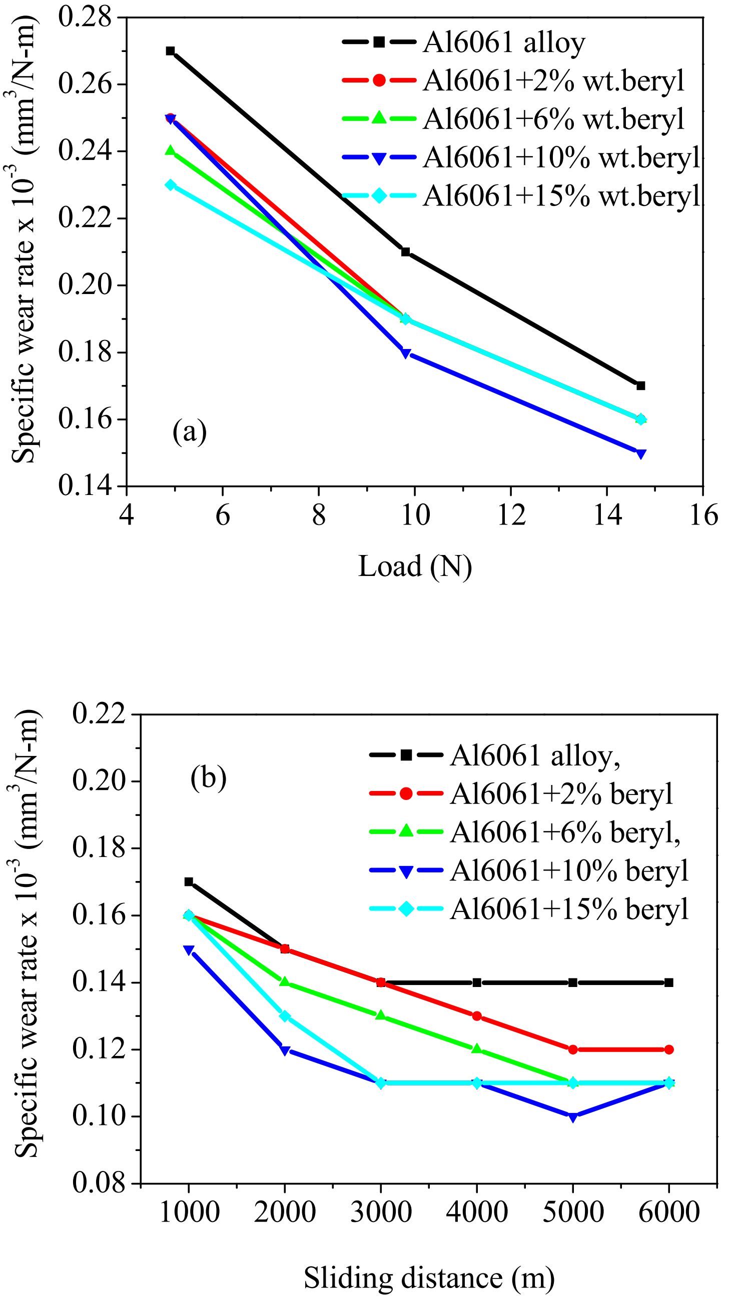


**Figure 1:** Hardness of Al6061 alloy and Al6061-beryl composites


Specific wear rate x $10^{-3}$ (mm$^3$/N-m)
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
4
6
8
10
12
14
16
Load (N)
(a)
Al6061 alloy
Al6061+2% wt.beryl
Al6061+6% wt.beryl
Al6061+10% wt.beryl
Al6061+15% wt.beryl
Specific wear rate x $10^{-3}$ (mm$^3$/N-m)
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
1000
2000
3000
4000
5000
6000
Sliding distance (m)
(b)
Al6061 alloy,
Al6061+2% beryl
Al6061+6% beryl,
Al6061+10% beryl
Al6061+15% beryl

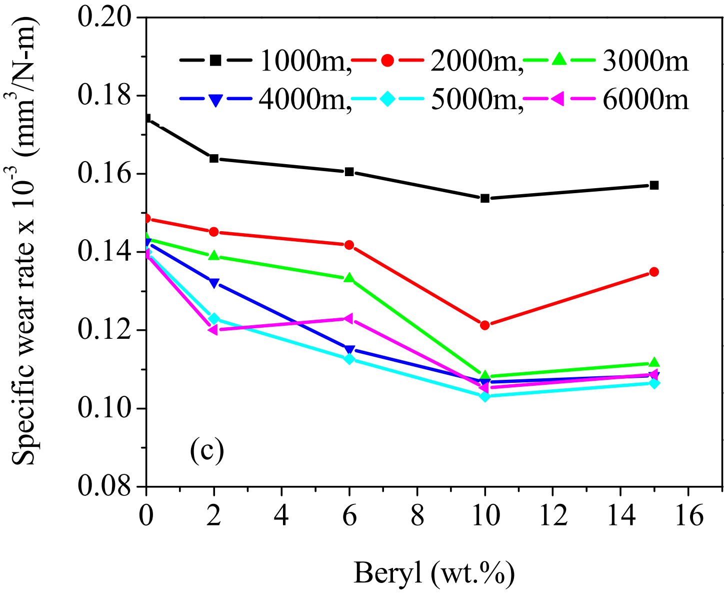


**Figure 2:** Effect of (a) load, (b) sliding distances (c) beryl content on the specific wear rate.

## 3. Results and discussions

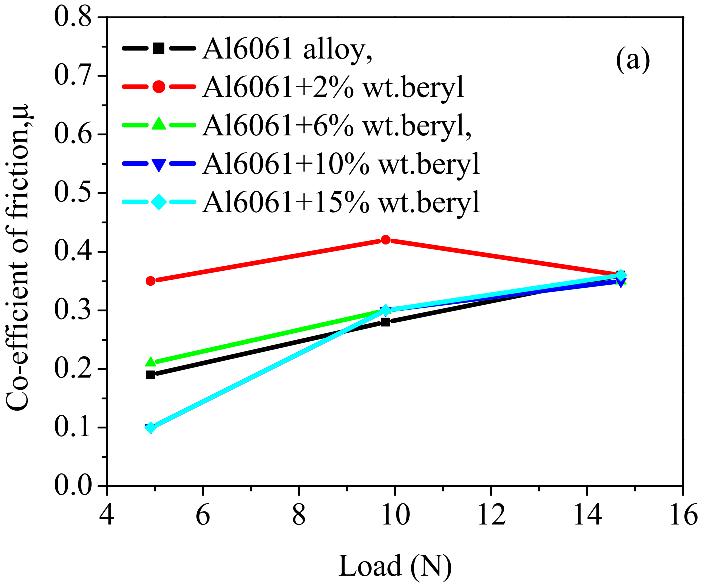
### 3.1 Hardness studies

Figure 1 shows a comparison of hardness of as-cast aluminum alloy and beryl-reinforced composites. It is observed that hardness of beryl reinforced composite is more than that of matrix alloy. The hardness of composite depends on the hardness of the reinforcement and the matrix.

### 3.2. Wear and Friction Studies

Figure 2(a-c) gives the specific wear rate (otherwise known as Lancaster wear coefficient) as a functions reinforcement, load and Sliding distance.

The values are in the range of 0.1741x 10$^{-3}$ to 0.1537x10$^{-3}$ mm$^3$/N-m. The specific wear rate decreased with load for all the materials, indicating improved wear resistance at the higher loads. Figure 2(b) gives the specific wear rate as a function of sliding distance. The values are in the range of 0.1741x10$^{-3}$ to 0.1031x10$^{-3}$ mm$^3$/N-m. The specific wear rate decreased with sliding distance for all the compositions indicating improved wear resistance for longer distances.



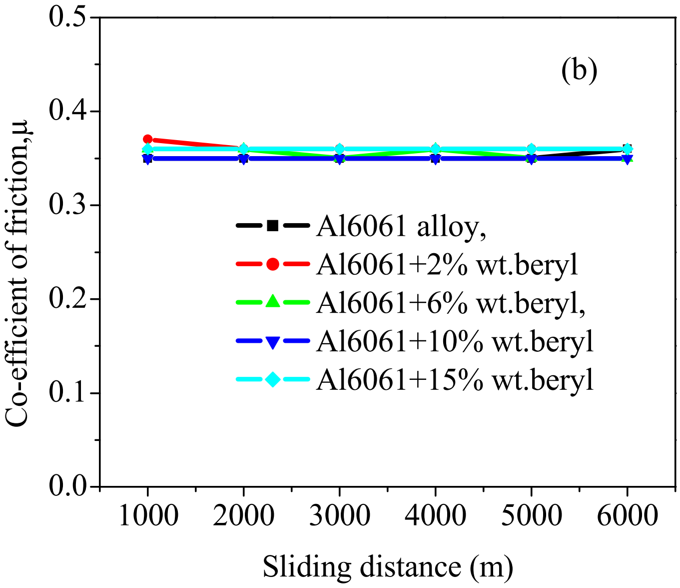
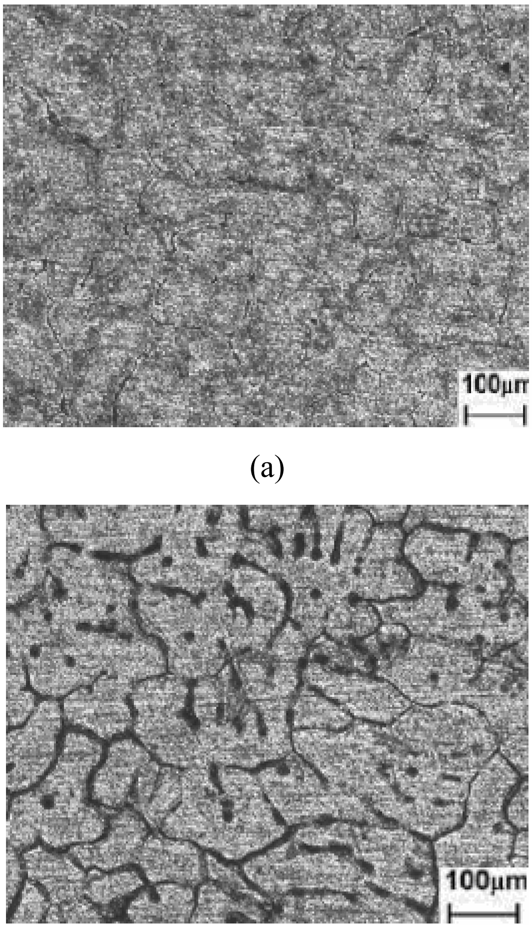


**Figure 3:** Variation of coefficient of friction with (a) load (b) sliding distance

From the analysis of figure 3(a) it can be concluded that the increase of the load leads to a significant increase of the friction coefficient. According to the Bowden and Tabor theory (Bowden, F.P (1986)), effects of the normal and tangential loads were considered separately. It was considered that the normal load determined the real area of contact, and to shear over this area, tangential force was needed. If the normal load is increased, then the real area of contact will increase along with tangential force. Hence, instantaneous value of coefficient of friction will also increase. The effect of the increase in sliding distance leads to a marginal decrease of the friction coefficient for fixed load and percentage of beryl, shown in Figure 3(b). During the initial stages, the surfaces of both the composite specimens and the steel counterpart were rough and thus strong ‘interlocking’ took place, resulting in a high friction coefficient. As the wear process continued, the rough profiles of the steel counterparts and the composite specimens were smoothened as a result of abrasion and a transfer film formed on the. The fluctuations in the coefficient of friction may be due to variation in contact between sample and disk. Composites have shown lower coefficient of friction in comparison to pure aluminum.

### 3.3 Microstructural studies

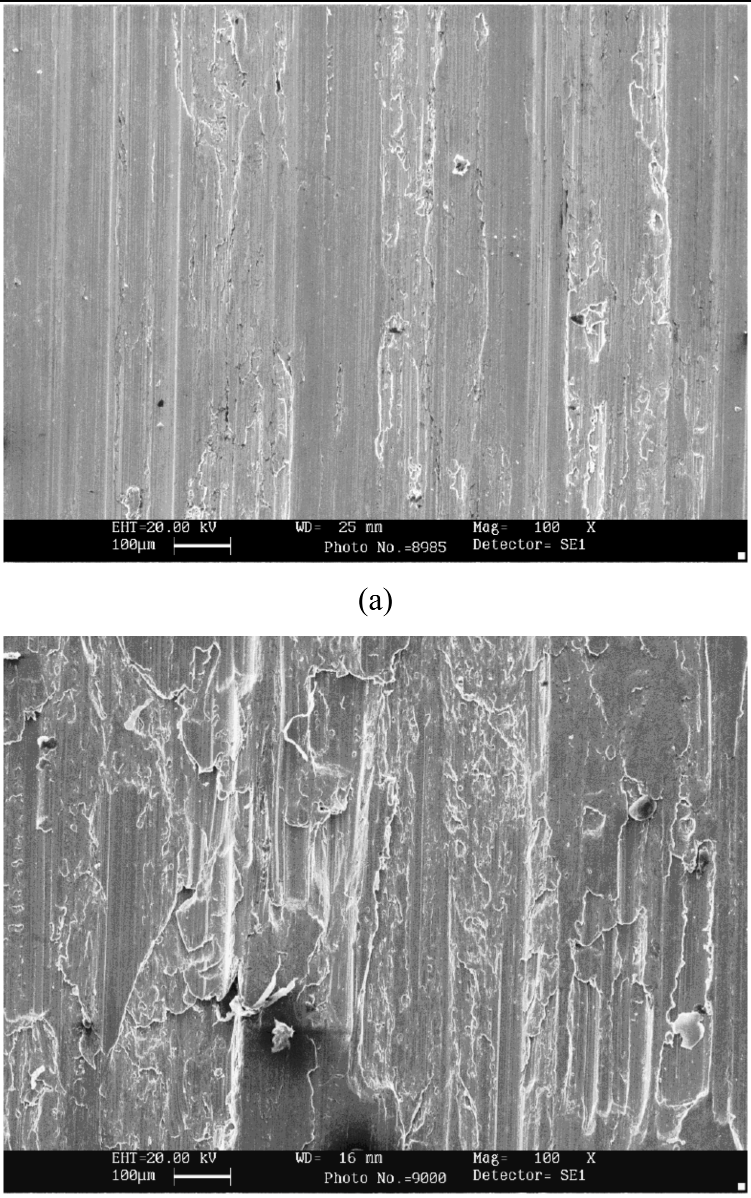


(a)

(b)

**Figure 4:** Microstructure of (a) Al6061 alloy (b) Al6061-10% beryl composite

Typical microstructures of the aluminum alloy and 10% wt. of beryl composites cast using cast iron die are shown in figure 4. It is observed from the figures that in the microstructure of the 10% wt. of beryl reinforced composite, the distribution of the beryl particles in the matrix is uniform and it is notable that there is no segregation of the particulates. An absence of segregation can be attributed to efficient and uniform mixing of the reinforcement in the stir casting.



(a)

(b)

**Figure 5:** Scanning Electron Micrograph (SEM) of worn surfaces of (a) Al6061 alloy (b) Al6061-10% beryl composites.

Figure 5 shows the scanning electron micrograph of worn surfaces of Al6061-10% beryl composite. A transfer layer of compacted wear debris along with the wear tracks can be observed over the sliding surface. This layer reaches a critical thickness before being detached resulting eventually in generation of wear debris. The extent of cover provided by this transfer layer is determined by the load, sliding speed and it increases with increasing load because of the increased frictional heating and hence better compaction. The other reason for lower wear rate in composites is their high hardness as compared to Al6061 alloy (H.N.Reddappa et.al., (2010)) resulting in lower real area of contact and therefore lower wear rate.Further examination of the worn surfaces of both the matrix (Al6061) and its composite

(Al6061-10% beryl) shows areas where material had been removed. As the load increased from lower to higher values, the morphology of the worn surface gradually changed from fine scratches to distinct grooves and flake craters. The specimen shows a mixed mechanism of fine scratches and larger grooves. There are indications of severe deformation and fracture resulting in more material loss (C.Yuvaraja et.al, (2008)).

## 4. Conclusions

The experimental study reveals following conclusions:

1. The wear rate is dominated by load factor, sliding distance and percentage of alumina factor. The increase of the load leads to a significant increase of the wear rate.
2. The specific wear rate increases linearly with the increase in normal load. However, the composites have shown a lower rate of wear for Al6061-10% beryl composites as compared to that observed in Al6061-2% beryl and Al6061-6% beryl composites.
3. The average coefficient of friction of Al6061-beryl composites decreases with increasing load.
4. The friction coefficient is highly influenced by load factor, sliding speed, and percentage of beryl. In addition, an increase in load leads to a significant increase of the friction coefficient.

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