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Investigation of anti-wear performance of automobile lubricants using thin layer activation analysis technique

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ABSTRACT

An investigation was carried out to examine the anti-wear behavior of automobile lubricants using thin layer activation analysis technique. For this study disc gears made of EN 31 steel were labeled with a small amount of radioactivity by irradiating with 13 MeV proton beam from a particle accelerator. Experiments on wear rate measurement of the gear were carried out by mounting the irradiated disc gear on a twin-disc tribometer under lubricated condition. The activity loss was monitored by using a NaI(Tl) scintillation detector integrated with a multichannel analyzer. The relative remnant activity was correlated with thickness loss by generating a calibration curve. The wear measurements were carried out for four different types of lubricants, named as, L1, L2, L3 and L4. At lower load L1 and L4 were found to exhibit better anti-wear properties than L2 and L3, whereas, L4 exhibited the best anti-wear performance behavior than other three lubricants at all the loads and speeds investigated.

1. Introduction

The reliability of industrial equipments, transportation systems and other machine parts can be significantly influenced by wear. The wear of these equipments can be controlled and minimizing by applying suitable gear lubricants. A gearbox is a vital component of many industrial applications. The gear lubricants are formulations, which are applied to prevent premature component failure, assure reliable operation, reduce operating cost, and increase service life. The important objectives accomplished by these lubricants include: reduction of friction and wear, corrosion prevention, reduction of operating noise, improvement in heat transfer, and removal of foreign or wear particles from the critical contact areas of the gear surfaces. The need of suitable technique for monitoring wear is usually based on three main factors, i.e., economics, safety and energy conservation. The wear of industrial components causes economic losses to the industry; it can compromise the safety of operating equipment by causing failure of parts. Wear monitoring can help in designing engineered surfaces, thereby increasing the working life of components, resulting in saving large sums of money, thus leading to conservation of material, energy and the environment. The conventional techniques such as gravimetric, micrometry, profilography, replica method are used for wear measurements in industry but these techniques have poor accuracy, low sensitivity and cannot be applied in all situations due to non-accessibility. Thin layer activation (TLA) analysis is a highly sensitive nuclear technique used for monitoring wear and corrosion phenomena employing radioactive tracer [1–21]. In this technique gamma emitting radioisotopes are introduced in-situ and distributed in a small area on the surface of interest of an engineering component [4,7,14,18]. The radioisotopes are removed from the surface along with the base element of the sample during the wear process. The material loss can be monitored either by monitoring the remaining radioactivity on the sample or by measuring the removed radioactivity from the sample using specific radioactive counting equipment [7]. The TLA technique has a number of advantages over other conventional techniques, such as high sensitivity in monitoring slow degradation process, offline as well as online measurement, simultaneous measurement of surface degradation of several components in the same machine, working with relatively low level of activity and quicker measurements [22]. Due to these advantages, the TLA technique is considered as a versatile technique for monitoring wear processes in several industrial components.

The objective of the present study was to compare four different types of mineral oil-based automobile lubricants [23] for their anti-wear behavior and to find out the best one, which can be

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applicable at different load and speed conditions. For this purpose, using TLA technique, the wear rates of disc gears made of EN31 steel were measured in presence of each lubricant at different experimental conditions.

2. Experimental

2.1. Proton irradiation

The disc gears samples made of EN31 steel (composition:1.1 wt % C, 0.52 wt% Mn, 0.22 wt% Si, 1.3 wt% Cr, 0.04 wt% S and 0.04 wt% P and 96.78 wt% Fe and dimension: outer diameter = 35 mm, thickness = 10 mm) (Fig 1) were irradiated with a 13 MeV proton beam using BARC-TIFR Pelletron accelerator facility, Mumbai. Each disc was irradiated under vacuum for 4 h with a collimated proton beam of 3 mm diameter having beam current of 200 nA. The radioactivity was confined to a circular zone of 3 mm diameter on the surface of the disc gear. After the completion of the irradiation, the disc samples were cooled for 10–15 days to allow decay of short lived radioisotopes, if any.

The major element in the disc gear is iron (Fe), which under goes nuclear reaction, when irradiated with proton beam of suitable energy. The nuclear reaction involved in this case is ^{56}Fe(p, n)^{56}Co. The nuclear data for this reaction is given in Table 1. The nuclear reaction has threshold energy of 5.446 MeV and cross section of 392 mb for 13 MeV proton. The product ^{56}Co has a half life of 77.3 days and gamma energies 846.77 keV (100%) and 1238.28 keV (67%). Throughout the experiment the count rate was measured from the area of 846.77 keV photopeak. The gamma energy spectrum of the activated disc gear was measured using an HPGe spectrometer and is shown in Fig. 2. All the observed peaks in the spectrum are the characteristic energies of ^{56}Co [24]. This indicates that, there was no other radionuclide byproduct produced in the process of irradiation. The proton energy chosen for irradiation has been decided on two factors; i.e., threshold energy and the cross section of the reaction involved. Both the Coulomb barrier and the Q-value of the nuclear reaction are deciding factor for the threshold energy of the nuclear reaction. Hence in such type of particle induced nuclear reaction, the kinetic energy of the projectile particle should be chosen in such a way that, it should be greater than the threshold energy and also the reaction cross section should be maximum at this energy. So that the irradiation time required will be less for producing certain amount of activity. The cross section value for ^{56}Fe(p,n)^{56}Co reaction is maximum for 13 MeV proton (Table 1), hence this energy of proton beam has been chosen for irradiation. The activities of the irradiated disc gears were measured using an HPGe gamma spectrometer and were found to be in the range 2.1–2.2 MBq.

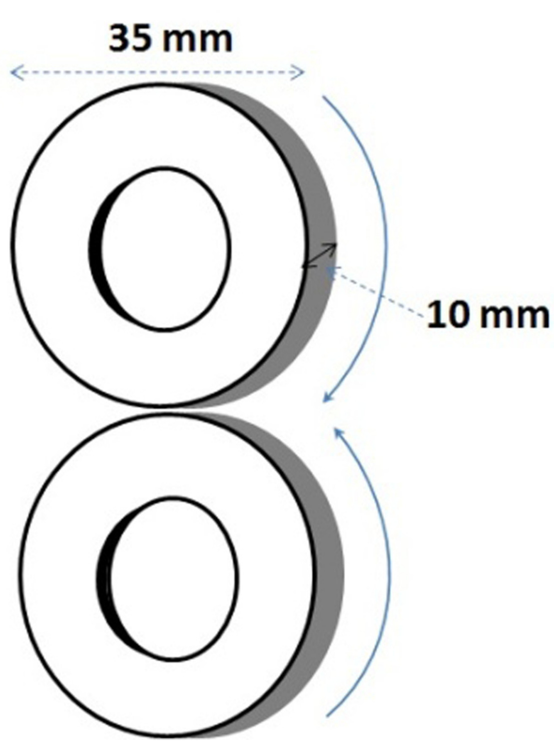

Fig. 1. Counter-rotating motion of two disc gears.

2.2. Determination of experimental calibration curve

In actual wear tests, the loss in radioactivity of investigated samples of interest is measured as a function of test time. There is a need to correlate the loss of radioactivity to material degradation as a consequence of wear in order to estimate the wear rate. For this purpose depth profiling was carried out by irradiating a stack of iron foils (Fe foils) of known thickness under identical beam parameters and geometry as used for irradiating the disc gears [1,18]. After completion of the irradiation, the radioactivity of the stacked foils was measured by removing one by one from the surface layer, by using NaI(Tl) gamma spectrometer. The calibration curve was obtained by plotting the relative remnant activity versus thickness removed. The detail description of estimation of relative remnant activity has been given in the Section 2.3. Fig. 3 shows a calibration curve generated by irradiating a stack of fifteen Fe foils, each having thickness 0.025 mm with a proton beam of 13 MeV energy and having 200 nA current for 4 h.

2.3. Wear measurements

The wear tests were carried out in an Amsler-type twin-disc tribometer, in which two identical disc gears were mounted on shafts located one above other. This type of tribometer is a standard type of machine, in which the real time gear contact can be simulated for wear and friction measurements. In the wear test, two discs rotate against each other on their cylindrical surface in counter-direction with contact width of 10 mm (Fig. 1). The proton irradiated disc was mounted on the upper shaft with the activated zone located at the contact point, as shown in Fig. 4a and Fig. 4b. To carryout wear experiments under steady-state conditions, initial running-in of the disc was carried out for 15 min at 10 kgf load and 200 rpm speed. Running-in is an initial subsurface conditioning process that often occurs when sliding or rolling contact is established between two solid bodies. Before mounting the disc on tribometer for actual wear test the radioactivity of the disc (counts/15 min) was measured for 15 min using the NaI(Tl) gamma spectrometer.

Four different mineral oil based automobile lubricants equivalent to SAE 80W90 grades (L1, L2, L3, L4) were produced by an oil company and they were tested for their anti-wear behavior. The properties of the lubricants are specified in Table 2. The anti-wear performance of different lubricants at various loads and rotating speeds were evaluated by measuring the extent of wear of the irradiated disc (upper) in presence of individual lubricant. At predetermined intervals the radioactivity labeled disc was removed from the tribometer, washed thoroughly with acetone, dried and the radioactivity was measured for 15 min using the gamma spectrometer (counts/15 min). Each measurement was repeated five times and the average count rate was estimated. The counting of disc gear samples and the stack foils were conducted with same instrument under identical detection geometries. The decrease in remnant activity on the disc with