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# Wear study of metallic interfaces for air-conditioning compressors under submerged lubrication in the presence of carbon dioxide

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ABSTRACT

The implementation of carbon dioxide ($CO_2$) as an alternative refrigerant for air-conditioning compressors has gained significant attention recently. The main interest in $CO_2$ is related to its zero ozone depletion potential (ODP) and low global warming potential (GWP) compared to commonly used hydroflurocarbon (HFCs) refrigerants such as R-134a. Friction and wear studies on tribological contacts commonly used in air-conditioning compressors under the presence of $CO_2$ are scarce in the literature. The present study focuses on the tribological behavior of Al390-T6, gray cast iron, and Mn–Si–brass (UNS C67300). These materials were tested against 52100 steel shoes using a pin-on-disk configuration. The tests were performed under submerged lubrication conditions using polyalkylene glycol (PAG) lubricant in the presence of $CO_2$. Results showed that the wear resistance of gray cast iron and Mn–Si–brass was higher compared to Al390-T6. In spite of the fact that Al390-T6 and Mn–Si–brass had similar hardness, Al390-T6 showed higher wear after testing. X-Ray Fluorescence (XRF) analysis of the lubricant after testing of Al390-T6 showed the presence of eutectic silicon particles. Also, Auger Electron Spectroscopy (AES) of Al390-T6 showed an atomic concentration decreased in silicon content after testing. Decreased in silicon content was attributed to the depletion of eutectic silicon particles, leading to a decrease in hardness and a subsequent increase in wear during the test.

## 1. Introduction

The concern about global warming grew in the 1990's and increased the interest of the refrigeration industries in natural refrigerants to replace HFCs (R-134a, R-407C, R-410a). Compared to HFCs (GWP of R-134a is approximately 3100), carbon dioxide ($CO_2$ or R744) has a negligible GWP and is inexpensive, nontoxic, and nonflammable. Also, among other natural refrigerants such as ammonia, water, air, and isobutene (R600a), $CO_2$ is the only one which can operate as a fluid in a vapor compression cycle at temperatures below 0 °C [1]. However, implementation of $CO_2$ imposes several disadvantages which include; loss of capacity, low coefficient of performance (COP) at high heat rejection temperature, and operation at very high pressures [1,2].

Polyalkylene glycol (PAG) has been proven to be the most effective lubricant candidate for $CO_2$ systems for different reasons including its partial solubility with $CO_2$ and excellent lubrication during starved conditions compared to other synthetic lubricants such as Polyolester (POE) [2,3]. Different studies were performed on different lubricants suitable for $CO_2$ systems and the researchers came to the conclusion that PAG offered the best lubricity effect for transcritical applications [4]. Metallic interfaces such as Al390-T6, Mn–Si–brass, and gray cast iron, are used in compressors, the first two being commonly found in swash plate type of compressors and the last one in scroll compressors, respectively. Even though research on the tribological aspects of these materials is abundant in the literature, the behavior of these materials under the presence of $CO_2$ is still missing. For instance, a tribological comparison of $CO_2$ and R-410a using synthetic lubricants such as PAG and POE under flooded lubrication conditions was performed [5]. By using Al390-T6 against 52100 steel shoes on a pin-on-disk configuration, they came to the conclusion that $CO_2$ performed better than R-410a in terms of the wear measured on the samples after testing. They also found that a transformed layer (mainly composed of oxides and silicon) 200 nm below the sliding surface of the disk, became harder during the initial stages of the test, but weaken during the end. Cannaday and Polycarpou [6], studied the advantages of $CO_2$ compared to R-410a using a pin-on-disk configuration. They claimed that $CO_2$ promoted stronger formation of oxide layers than R-410a in the presence of POE under submerged lubrication conditions. In addition, an increase in the oxygen and silicon content through the

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testing was found when compared to the virgin state, yet there was no conclusive trend in the behavior due to the variability in the percentages of these two elements. The tribological performance of $CO_2$ against R-134a using a pin-on-disk configuration made out of gray cast iron was studied [7]. It was not only found that $CO_2$ performed similarly in terms of wear and friction compared to R-134a under unlubricated conditions, but under boundary/mixed lubrication conditions using PAG lubricant. Nunez et al [8] published a direct comparison among Al390-T6, Mn–Si–brass, and gray cast iron, under boundary-mixed lubrication conditions using PAG. It was found that even though Mn–Si–brass has a lower mechanical strength compared to gray cast iron, they performed similarly and were superior in terms of scuffing resistance (load up to the point of failure) compared to Al390-T6. In that study the scuffing point was characterized by a sudden increase in the friction coefficient.

The objective of this work is to compare the wear performance of Al390-T6, Mn–Si–brass, and gray cast iron under submerged (flooded) lubrication conditions in a $CO_2$ atmosphere and PAG lubricant. Tests were performed using a High Pressure Tribometer (HPT) which is a machine designed to perform tribological tests at high chamber pressures, details of the HPT can be seen in Fig. 1 [9]. The disks were tested against 52100 steel shoes using a pin-on-disk configuration. Wear type of experiments are useful for direct comparison of different environments or different materials (like in the current study). During these experiments the load is kept constant throughout the test. After testing, the variation of surface roughness with burnishing/wear was also investigated. Specifically, statistical parameters related to amplitude, as well as bearing area descriptors (such as lubricant retention index [2,10]) were extracted for the untested and burnished samples. Lastly, XRF was performed to analyze the PAG lubricant and Auger spectroscopy (AES) was employed to compare the change in atomic concentration of the chemical elements of the different interfaces after the experiments, respectively.

## 2. Experimental procedure

### 2.1. Controlled tribological experiments

Using a pin-on-disk configuration, one set of experiments was designed and performed. During this set, the load was kept constant throughout the tests in order to study the wear performance of the different tribopairs. PAG lubricant (Idemitsu Kosan Co., Ltd. PZ 68ZL) was used (chemical composition of PAG can be found on [11]). This lubricant was specifically manufactured for use with $CO_2$ as a refrigerant. A constant normal load of 1340 N was used for 20 min and the interface was submerged in a pool of PAG lubricant. The $CO_2$ pressure was kept constant at 1.4 MPa, the temperature at 90 °C, while the rotational speed was set constant at 1000 rpm (which corresponds to a linear speed of 2.4 m/s). The normal load and the duration of the tests were selected in such a way that under the conditions of submerged lubrication and contact geometry wear was caused on the surface of the disks. The chamber pressure was maintained at 1.4 MPa (~200 psi) to avoid damage of the sealing of the tribometer. The chamber temperature of 90 °C was selected to simulate the behavior of compressors under idle conditions.

Before initiating a test, the samples were immersed in a pool of acetone and ultrasonically cleaned, then rinsed with alcohol and dried using warm air. In order to ensure repeatability each experiment was performed twice. In the contact geometry used for these experiments, the pin (shoe) was the lower stationary part, while the disk was the upper rotating part (see Fig. 1). Typical

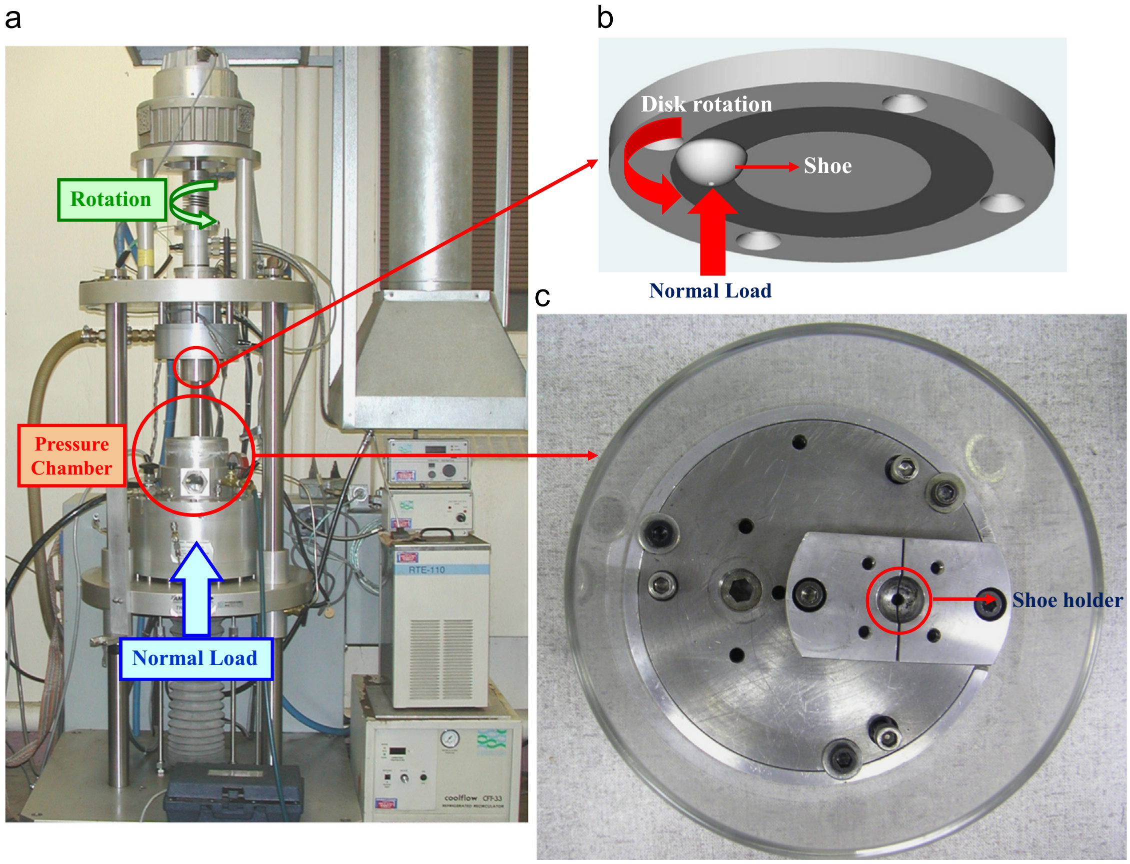

**Fig. 1.** Details of the High Pressure Tribometer (HPT); (a) schematic of the equipment; (b) sliding interface; and (c) details of the shoe holder.