in air conditioning systems in a scientific and practical manner."

Dr. Walther Emil Ludwig Mathesius, president and director of the Geneva Steel Company, Geneva, Utah, received the Francis J. Clamer Medal for outstanding achievements in the field of metallurgy, particularly for contributions in blast furnace practice.

The George R. Henderson Medal was awarded to Joseph Burroughs Ennis, senior vice-president, American Locomotive Company, New York, "in consideration of his accomplishments in locomotive engineering and important contributions in the field of locomotive design."

For his paper on "The Theory of Suspension Bridges," which appeared in the March and April, 1943, issues of the *Journal of the Franklin Institute,* Professor Stephen P. Timoshenko, department of theoretical and applied mechanics, Stanford University, Palo Alto, Calif., was awarded the Louis E. Levy Medal.

A Certifiicate of Merit was given to the Western Union Telegraph Company, New York, "for the development of the reperforator switching system, a contribution to the greater accuracy and speed of telegraphic service."

HENRY BUTLER ALLEN,
Secretary and Director, the Franklin Institute

SPECIAL ARTICLES

THE INFLUENCE OF IRON OXIDE ON WEAR OF RUBBING SURFACES

IN the course of an investigation of wear under boundary lubrication the condition was produced which permits hard and soft ferrous surfaces to rub under very heavy loads at a moderate speed without rapid wear despite the absence of special wear-inhibitors in the hydrocarbon lubricant. The tenacious layers of iron-oxide which slowly develop under the lubricant and cover the rubbing surfaces were studied with the aid of a microscope and their ability to reduce wear was related to the hardness or imbedability of the surfaces. The following summarizes some of the experiments:

In the first experiments a modified Timken machine[1] was used, in which a stationary block of mild steel or of cast-iron, with a wearing face measuring one by ten millimeters was aligned with its longer edge perpendicular to the direction of rotation of a polished hard steel cylindrical ring measuring five centimeters in diameter by ten millimeters wide. The ring was turned upon its axis with a peripheral speed of 209 centimeters per second while pressure was applied to the block and a plentiful supply of lubricant flowed over both parts.

Failure due to the adhesion and transfer of metal from the block to the ring by welding would occur instantly unless the apparent bearing pressure was very light (20 to 30 kg/cm^2). If the initial pressure was gradually increased from this low figure, a worn-in state could be developed, in the course of several days, whereby a pressure of 2 or 3 thousand kilograms per square centimeter could be borne without failure. Wear-in or break-in was materially assisted by frequently repolishing the ring to remove particles of metal which had been transferred to it. No attempt was made to polish the block. After the break-in process was complete, welding ceased and further polishing was not necessary.

The rate of wear of a properly broken-in mild-steel or cast-iron block was so low that no loss of weight could be detected by reweighing the block to 0.2 mg after a day or two of high-pressure operation (2,000 to 3,000 kg/cm^2). In some experiments a slight gain in weight of both the ring and the block was noticed after prolonged operation; this is attributed to the accumulation of iron-oxide.

In further experiments similar attempts to break-in hard steel blocks were unsuccessful; failure occurred from seizure at pressures below 800 kg/cm^2.

Observations of a similar type were made during experiments with the four-ball wear machine, an adaptation of Boerlage's apparatus.[2] In this machine, three stationary balls of hard steel, of cast iron or of mild-steel clamped in a cup and covered with the lubricant, were pressed upward with a measured force against a hard steel ball spinning on a vertical axis. When heavy loads (60 kg or more) were applied, there was an immediate transfer of metal to the spinning ball, and rapid wear of the stationary balls occurred when an ordinary mineral oil was the lubricant at these loads. However, with a very light load (7 kg), no welding was observed; the sliding action appeared to be smooth, and the wear occurring could be determined by measuring scar diameters at predetermined intervals of time. Such measurements are given in Table 1.

During the break-in period the contact areas of the soft stationary balls rapidly expanded, probably by plastic flow, until the contact pressures reached the approximate range of 2,000 to 3,000 kg/cm^2, depending upon temperature. However, the scars in the more elastic stationary balls did not expand so rapidly

[1] Timken Roller Bearing Company, Canton, Ohio.

[2] *Engineering*, 136: 46, 1933; 144: 1, 1937.

at first, but wore continuously until at length they had become much larger, and the pressures much smaller than in the softer balls.

The red and brown material reported in the table has been identified as iron-oxide produced in the wearing areas by friction-oxidation. Microscopic observation revealed that the oxide became imbedded in the softer metals but not in hard steel. Well-established iron-oxide deposits were also observed on the broken-in mild-steel and cast-iron wear blocks of the Timken machine, but not on the hard steel blocks which failed to break-in. The observations indicate that the presence of these oxide layers on soft metal balls must have contributed materially to the low rate of wear after break-in, and the absence of oxide from hard steel balls permitted continuous wear without the occurrence of break-in.

It is apparent from the work of Bowden, Hughes and Whittingham[3] that fresh ferrous surfaces operate in danger of seizure owing to the high coefficient of boundary friction; such seizure results in the establishment of metal bridges which have the shear strength of the metal involved. On the other hand, if a contaminating film of oxide, sulfide, halide, etc., exists, shearing occurs along the plane of the mechanically weaker contaminant and friction is reduced.

The experiments of Bowden and Tabor[4] indicate that the area of intimate contact of lightly loaded sliding surfaces is very small, and at local areas the pressure may exceed the elastic limit and cause steel to flow plastically. It would seem, therefore, that despite the light initial load, local conditions in the Timken machine were essentially the same as in the four-ball machine where the calculated initial contact pressure at 7 kg load approached the elastic limit of the hard, and far exceeded that of the soft steel balls.

TABLE 1

THE RELATIVE RATES OF WEAR OF HARD AND SOFT STATIONARY BALLS IN THE FOUR-BALL WEAR MACHINE

Conditions: Speed, 700 rpm (31 cm/sec); load, 7 kg; lubricant, SAE 20 motor oil, air saturated; rotating ball of hard steel, stationary balls as listed.

Elapsed minutes operation	Mild steel stationary balls (200 Brinell)			Cast-iron stationary balls (230 Brinell)			Hard steel (SKF) stationary balls (630 Brinell)		
	Average diameter of six scars, mm	Scar pressure kg/cm²	Appearance of scars*	Average diameter of six scars, mm	Scar pressure kg/cm²	Appearance of scars*	Average diameter of six scars, mm	Scar pressure kg/cm²	Appearance of scars*
				Lubricant Temperature, 30° C.					
5	.316	3,640	Reddish brown	.282	4,580	Reddish-brown	.214	7,950	Polished steel
10	.336	3,220	"	.292	4,270	"	.225	7,190	"
20	.349	2,990	"	.310	3,790	"	.254	5,640	"
40	.340	3,150	Brown	.322	3,510	"	.272	4,920	"
80	.344	3,250	"	.342	3,110	"	.347	3,020	"
160	.340	3,150	Dark brown	.345	3,060	"	.431	1,960	"
320	.341	3,130	"	.340	3,150	"	.437	1,910	Slightly reddish
640	.373	2,620	"	.390	2,390	"	.438	1,900	Reddish-brown
				Lubricant Temperature, 130° C.					
5	.499	1,460	Reddish-brown	.413	2,130	Reddish-brown	.332	3,300	Polished steel
10	.518	1,360	"	.425	2,010	"	.395	2,330	"
20	.525	1,320	"	.434	1,930	"	.486	1,540	"
40	.528	1,310	"	.450	1,800	"	.601	1,010	"
80	.547	1,220	"	.484	1,550	"	.701	741	"
160	.598	1,020	"	.544	1,230	"	.763	625	"
320	.633	908	"	.565	1,140	"	.893	456	"
640	.645	875	"	.584	1,070	"	1.04	336	"

* Dark field illumination at 30 or 60 diameters.

The mechanism controlling the surface events which determine whether a new bearing shall fail or shall become broken-in to carry heavy loads is visualized as follows: At low initial loads where the destruction of the bearing surface by seizure can be avoided, the heat of mild rubbing accelerates the oxidation of iron in the surface by oxygen dissolved in the lubricant. If the surface is imbedable, the resulting oxide becomes established as a protective layer in much the same way as reported by Eichinger for unlubricated surfaces.[5] Rubbing now occurs over the oxide layer and the ferrous surface beneath is thus prevented from having direct contact with oxygen activated by rubbing. Hence further friction-oxidation decreases to the vanishing point.

Hard steel surfaces, not being receptive to foreign materials, remain bare during rubbing and subject to attack by oxygen, leading to continuous removal of metal or wear. On the other hand, the softer metals

[3] Bowden and Hughes, *Proc. Roy. Soc.*, A–172: p. 263, 1939. Hughes and Whittingham, *Trans. Faraday Soc.*, 38: p. 9–27, 1942.

[4] Bowden and Tabor, *Proc. Roy. Soc.*, A–169: 391–413, 1938.

[5] Eichinger, Eidgenöss. Materialprufüngs-u. Versuchsanstalt Ind., Bauw. Gewerbe, Zurich Diskussionsber No. 121, 32 pp., 1938.

become coated and resistant to further wear, as the data illustrate.

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ISOLATION OF A NEW LACTOBACILLUS CASEI FACTOR

SNELL and Peterson[1] first presented evidence for the existence of a new growth factor (the "norite eluate" factor) for *Lactobacillus casei*. Mitchell, Snell and Williams[2] reported the concentration of a factor ("folic acid") from spinach. This factor was active for both *Streptococcus lactis* R and for *L. casei*. Hutchings, Bohonos and Peterson[3] showed that purified concentrates of the "norite eluate" factor from liver stimulated the growth of *Lactobacillus helveticus, Lactobacillus delbruckii, Propionibacterium pentosaceum* and *Streptococcus lactis* R.

Since then a number of different compounds have been described which are active in stimulating the growth of *L. casei* or *S. lactis* R. Pfiffner[4] *et al.* reported the isolation from liver of a crystalline compound which was active for *L. casei*. This substance which they designated vitamin B_c was also active in preventing anemia and in promoting growth in chicks. Stokstad[5] described two compounds; one was obtained from liver and the other from yeast. That obtained from liver was thought to be identical with the compound obtained by Pfiffner *et al.* The free acids of the compounds obtained from liver and yeast had equal potency for *L. casei*. However, when assayed with *S. lactis* R the preparation from yeast was only half as active as from liver. Both the factors from liver and yeast appear to be different from the growth factor for *S. lactis* R described by Keresztesy *et al.*[6] Their preparation was approximately 2,500 times as active for *S. lactis* R as for *L. casei*.

In this communication we wish to report the isolation in crystalline form of a new compound which is active for *L. casei* and *S. lactis* R and is also active in the nutrition of the chick. This new compound was crystallized as the barium salt, as the free acid and as the methyl ester. The barium salt crystallized as needles, the free acid and the ester crystallized as small needles or threads. The absorption spectrum in 0.1 N NaOH was very similar to the compound isolated from liver (Table 1). It will be noted that the $E_{1\,cm}^{1\,per\,cent.}$ was less for the new compound, being only 86 per cent. as great at 365 mμ.

TABLE 1
COMPARISON OF ABSORPTION SPECTRA

	New compound		Liver compound		Ratio $\frac{E_{1\,cm}^{1\,per\,cent.}\ \text{New compound}}{E_{1\,cm}^{1\,per\,cent.}\ \text{Liver compound}}$
	mμ	$E_{1\,cm}^{1\,per\,cent.}$	mμ	$E_{1\,cm}^{1\,per\,cent.}$	
Maxima ...	259	317	255	440	0.72
Minima ...	266	305	267	376	0.81
Maxima ...	280	333	283	425	0.78
Minima ...	332	92	331	103	0.89
Maxima ...	365	130	365	151	0.86

This new compound was 85 to 90 per cent. as active as that from liver when assayed with *L. casei*, but only 6 per cent. as active as the liver compound by *S. lactis* R assay. The amounts of the liver compound required for half-maximum growth were 0.000055 micrograms per ml for *L. casei* and 0.00025 micrograms per ml for *S. lactis* R. The new compound was required in amounts of 0.000061 micrograms per ml for *L. casei* and 0.0042 micrograms per ml for *S. lactis* R.

On the basis of their absorption spectra the three *L. casei* factors (present compound, liver and yeast factors) appear to be different from "folic acid." The $E_{1\,cm}^{1\,per\,cent.}$ for this new compound and the liver *L. casei* factor were determined at pH 11.0 and compared with the data at the same pH reported by Mitchell[7] (Table 2). The wave-lengths chosen do not represent maxima or minima but were used to correspond with the wave-lengths reported for folic acid.

TABLE 2
COMPARISON OF $E_{1\,cm}^{1\,per\,cent.}$ AT pH 11.0 OF THE L. CASEI FACTORS AND FOLIC ACID

	New compound	Liver compound	Folic acid
mμ	$E_{1\,cm}^{1\,per\,cent.}$	$E_{1\,cm}^{1\,per\,cent.}$	$E_{1\,cm}^{1\,per\,cent.}$
260	296	404	338
280	336	410	190
300	245	334	102
380	121	125	92

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[6] J. C. Keresztesy, E. L. Rickes and J. L. Stokes, SCIENCE, 97: 465, 1943.

[7] H. K. Mitchell, *Jour. Am. Chem. Soc.*, 66: 274, 1944.