AD/A-005 476

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Army Foreign Science and Technology Center
Charlottesville, Virginia

31 December 1974

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TRANSLATION

In Reply Refer to:
FSTC-HT-23- 896-73
DIA Task No. T70-23-01

Date: 31 December 1974

ENGLISH TITLE: EXPERIENCE GAINED IN THE USE OF NI-RESIST INSERTS IN ENGINE CYLINDERS

SOURCE: Avtomobil'naya promyshlennost', No. 8, 1972, pp. 3-6

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LANGUAGE: Russian

COUNTRY: USSR

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## NOTICE





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Translated by James McVay
for D. Firer
FSTC-HT-23-896-73

# EXPERIENCE GAINED IN THE USE OF NI-RESIST INSERTS IN ENGINE CYLINDERS

Authors: M. A. Grigor'yev, N. N. Ponomarev, Ye. I. Shanin (Central Scientific Research Institute of Automobiles and Automobile Engines)

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Research has shown that during operation of a number of domestic engines a major portion of the wear is caused by abrasive particles which enter the engine by various routes: i. e. cylinder wear during operation is primarily abrasive in nature, not corrosive. [1, 2]. Therefore, in order to determine the reasons for the enhanced wear resistance of Ni-resist inserts in comparison with grey cast iron, results of tests previously conducted were examined and analyzed, and some additional investigations were made.

From 1946 to 1950 the Gor'kiy Automotive Plant conducted yearly monitoring tests of GAZ-51 engines in operation [3]. After 15 to 38 thousand kilometers cylinders incorporating inserts exhibited 2.0 to 3.7 times less wear than cylinders without inserts. Piston ring wear decreased from 1.2 to 3 times.

In 1966 Gor'kiy tested 11 M-21 engines installed in taxicabs [4]. Kilometerage of the engines varied from 46 to 103 thousand kilometers. It was found that use of Ni-resist inserts decreased cylinder sleeve wear by a factor of 2.5 on the average (3.02 μ/1000 km and 1.22 μ/1000 km, respectively). Piston ring wear decreased by a factor of 1.35 to 2.86.

In a 1962 test of eleven MZMA-407 engines in taxicabs the wear resistance of cylinders with inserts was 1.3 times greater than cylinders without inserts.

In 1969 the Moscow Automotive Plant *imeni* Likhachev tested a ZIL-130 engine in a truck in conventional operation [5]. After 50 thousand kilometers wear in the upper portion of sleeves without inserts was approximately 5 times greater than for sleeves with inserts.

In 1969 and 1970 the Central Scientific Research Institute of Automobiles and Automobile Engines (NAMI) tested two ZIL-130 engines in conventional operation in ZIL-MMZ-555 trucks. In both engines after 40 to 46 thousand kilometers the amount of wear for cylinder sleeves having inserts was 2.1 times less than for those without inserts (fig. 1). In cylinders without inserts increased ring wear, particularly for the first and second compression rings, was observed as a result of deterioration of the chromium coating.

During road tests of the ZIL-130 engine conducted under various conditions in 1970 (heavy city traffic, "stop and go" driving, acceleration and coasting, and constant-speed driving) the amount of wear after 19,480 km for sleeves without inserts was 2.1 times greater than for cylinders with inserts.

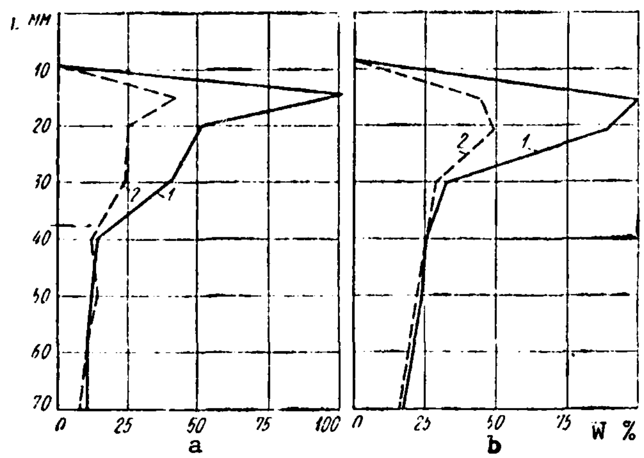


Fig. 1. Wear W of Cylinder sleeves of Zil-130 engines after tests by NAMI (L is the distance from the block upper surface): a. First engine; b. Second engine; 1. Sleeves without inserts; 2. Sleeves with inserts.

Data on the decrease in cylinder sleeve and piston ring wear with use of Ni-resist inserts are given in Table 1. The data show a significant increase in the wear resistance of cylinders incorporating Ni-resist inserts. These data, however, do not permit determination of the cause of this increase since during operation cylinder wear is affected by a number of factors which cannot be differentiated in measuring wear incurred over an extended operating period. Wear ocurring during bench tests at normal temperatures and under varying speed and load conditions was virtually identical for cylinders with and without inserts and was much smaller than operational wear. Consequently, the

Table 1
Part wear during operation of cylinders with and without inserts

| Engine model | Cylinders | Piston rings | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | Scraper |
| Operating tests | | | | | |
| GAZ-51 | 2.0-3.7 | 2-3 | 1.3-1.5 | - | 1.2-1.3 |
| ZMZ-21 | 2.5 | 2.9 | 1.3 | - | 1.3 |
| MZMA-407 | 1.3 | - | - | - | - |
| ZIL-130 | Up to 5 | - | - | - | - |
| ZIL-130 | 2.1 | 3.5-5.6 | 2.2-5.0 | 1.1-1.3 | 1.6-1.7 |
| Road tests | | | | | |
| ZIL130 | 2.1 | - | - | - | - |

decrease in wear of cylinders with Ni-resist inserts during operation is due to factors which substantially affect wear and are absent during conventional bench tests conducted in accordance with GOST 491-55 or GOST 14846-69. These factors primarily involve corrosive wear of engines operating under predominantly low temperature conditions and abrasive wear, which occurs when dust enters the engine.

The explanation for the enhanced wear resistance of cylinders incorporating Ni-resist inserts is usually based on the hypothesis that the corrosive form of wear predominates during operation. This hypothesis is based on a large number of experiments in which the amount of wear at low temperatures was substantially (approximately 5 times) higher than at a normal temperature. However, when conducting bench tests of this type, the amount of cylinder wear at a low oil and water temperature is usually less than in ordinary operation [6,2].

Data from laboratory tests of samples of materials in solutions of various acids are also presented as proof of the increase in wear resistance of cylinders due to the anticorrosion properties of Ni-resist inserts employed. For example, Ni-resist samples tested in a sulphuric acid solution are 500 times more stable than grey iron, while samples tested in an acetic acid solution are 30 to 60 times more stable [7]. It is also known that chrome silicon iron samples are less stable than Ni-resist by a factor of several tens, but the wear resistance of chrome silicon iron sleeves during engine operation is 2 to 4 times less than that of Ni-resist. In view of this, doubts have arisen about the enhanced wear resistance of cylinders with inserts supposedly resulting from the high corrosion resistance of Ni-resist. Special research has been performed to explicate this problem.

During tests conditions for intensification of corrosive wear were artificially created, although they were not characteristic of operating conditions.

From 60 hour tests of the ZMZ-53 engine conducted by NAMI in 1970 it was established that the wear resistance of sleeves incorporating inserts was only 1.2 times higher than for grey iron sleeves under such conditions (fig. 2a).

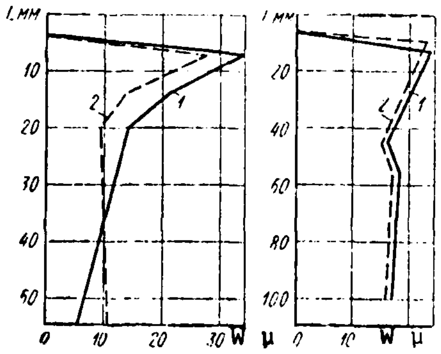


Fig. 2. Engine cylinder wear following low temperature tests: a. ZMZ-53 engine; b. UAZ-450 engine; 1. Cylinders without inserts; 2. Cylinders with inserts.

Wear incurred in sleeves with and without inserts at the Gor'kiy Automotive Plant in 100 hours of tests on the UAZ-450 engine at a water temperature of 10° to 15°C and an oil temperature of 35° to 4[illegible] C with frequent starts and stops was approximately identical (Fig. 2b) [8].

In the 1969-1970 winter NAMI tested the ZIL-130 engine in "stop and go" and "peak hour" driving. 713 starts were made. Total distance traveled was 3453 km. After the tests, wear of sleeves without inserts was 1.2 times greater than that of sleeves incorporating inserts (6.1 and 5.3 microns, respectively).

In 1969 oil from 15 Fiat 124 engines, of which nine had inserts installed and six did not, were tested. The tests were conducted under "stop and go" and "peak hour" conditions during the period between 20 January and 6 April at generally low ambient temperatures (-35° to +5°C).

Each engine was started 1,967 times during the tests. Distance traveled was 12,100 km. Average maximum cylinder wear was 4.2 μ for engines without inserts and 3.1 μ for engines with inserts. Wear was measured by micrometer, and insignificant variations in dimensions could be caused by cylinder deformation.

In 1969 the Volga Automotive Plant tested eight VAZ 2101 engines (four engines with inserts, four without) under "stop and go" and "peak hour" conditions between 30 January and 10 April at ambient temperatures from -40° to +5°C. After 10,196 km and 1,362 starts the average wear was virtually identical (10 μ) for sleeves both with and without inserts.

For comparison, results of similar tests on nine Fiat 124's mounting engines without inserts using various domestic oils may be introduced. The tests were conducted in Elektrogorsk during the winter of 1970 by the All-Union Scientific Research Institute of the Petroleum Industry with NAMI participation. The vehicles traveled 10,750 km and underwent 1,160 cold starts during the tests. Average cylinder wear during the test period for all engines was 6 to 8 μ.

NAMI tested oils on a one-cylinder engine (a section of a ZIL-130 engine) of the NAMI-1 unit with and without inserts. The engine was tested for 120 hours under operating conditions used to test oils for low temperature deposits [8]. During these tests wear of sleeves without inserts was 1.05 times greater than for sleeves with inserts.

During combustion of fuel in cylinders of modern engines conditions are created for formation of oxides of nitrogen which can form a nitric acid solution by combining with condensed water. In order to determine how nitric acid in combination with low temperature conditions affects cylinder sleeve wear, bench tests were conducted in which a 4.3% solution of nitric acid was fed to the intake manifold of a ZIL-130 engine in which four cylinders had inserts and four did not. The engine was idled 40 hours at 1,200 rpm. Water temperature was maintained at 30°C, and oil temperature at 45°C. Each hour 400 $cm^3$ of the nitric acid solution was fed to the intake manifold through a dripcock. The amount of cylinder wear was great; however, the wear of cylinders with and without inserts differed by a factor of 1.2.

For clarity the results of these tests for corrosive wear of cylinders with and without Ni-resist inserts are given in Table 2.

Cylinder wear during low temperature tests

| Engine model | Type of test | Duration | Cylinder wear in μ | | Wear ratio |
|---|---|---|---|---|---|
| | | | With inserts | Without inserts | |
| ZMZ-53 | Bench | 60 hrs | 29.0 | 36.4 | 1.25 |
| UAZ-450 | Bench | 100 hrs | 23.0 | 23.0 | 1.00 |
| ZIL-130 | Road | 3453 km with 713 starts | 5.3 | 6.1 | 1.20 |
| Fiat 124 | Road | 12,100 km with 1967 starts | 3.1 | 4.2 | 1.25 |
| VAZ-2101 | Road | 10,196 km with 1362 starts | 10 | 10 | 1.00 |
| NAMI-1 | Bench | 120 hrs | 19.3 | 20.4 | 1.05 |
| ZIL-130 | Bench | 40 hrs (nitric acid) | 108 | 130 | 1.2 |

The data as a whole show that under extremely low temperature conditions rarely encountered in operation cylinders incorporating Ni-resist inserts undergo ~20% less wear than cylinders without inserts. Therefore, the doubling of cylinder wear resistance under ordinary operating conditions when Ni-resist inserts are employed is primarily caused by factors other than their high corrosion resistance.

When Ni-resist inserts were introduced at the end of the 1940's, engines operated on low-octane gasoline with a sulphur content as high as 0.6%, which increased corrosive wear of cylinders. A decrease in corrosive wear of cylinders was effected by using alkaline additives in modern oils which counteracted the effect of acid products (fig. 3).

Thus corrosion resistance could have had a greater effect on the total wear during operation of older model engines than newer.

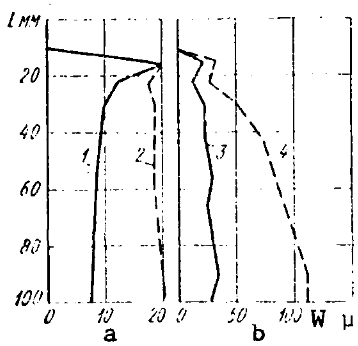


Fig. 3. Cylinder wear during tests with various oils in a one-cylinder engine (a) and a ZIL-130 engine (b): 1. AS-8 oil with additive; 2. AS-8 oil without additive; 3. DSP-8 oil (GOST 10541-63); 4. AK-10 oil (GOST 1862-60).

The comparitively moderate (up to 20%) increase in the wear resistance of cylinders incorporating Ni-resist inserts obtained under low temperature conditions of engine operation could not be the only reason for the increase in wear resistance of such cylinders during ordinary operation by a factor of two or more. It was therefore hypothesized that this increase was primarily due to the abrasive resistance of Ni-resist.

When Ni-resist inserts were introduced, the abrasive resistance of Ni-resist was not seriously checked with the exception of tests conducted on Ni-resist samples in an Amsler machine [7] in which the Ni-resist abrasive resistance was less than for grey iron. However, the conditions for these tests were rather remote from cylinder operating conditions in actual engines.

Subsequently, bench tests in which quartz dust was fed to engines were conducted.

The Gor'kiy Automotive Plant tested UAZ-450 engines by artificially feeding measured amounts of quartz dust to the intake manifold of each cylinder [9]. Simultaneously, dust was introduced into the engine crankcase in an amount calculated as 50% of that fed to the cylinders. After 100 hours of tests conducted at full power and normal temperature, it was established that cylinders with Ni-resist inserts incurred 1.6 times less wear than those without inserts (fig. 4a).

NAMI conducted tests of a ZIL-130 engine in which dust was fed to the air filter in the amount of 1 gram of dust per 1 $m^3$ of air. After 150 hours of tests at 50% rated rpm and load, cylinders with inserts exhibited 1.4 times less wear than cylinders without inserts (fig. 4b).

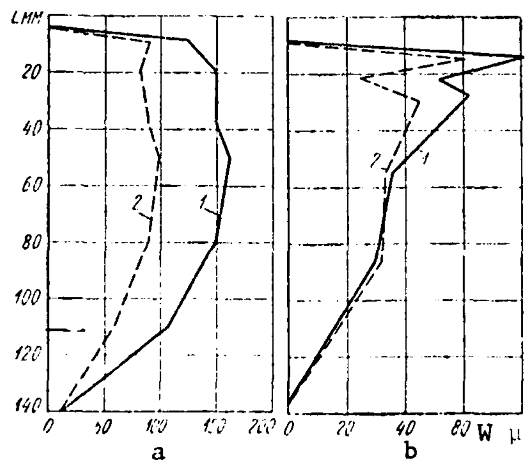


Fig. 4. Cylinder wear during tests for abrasive wear in engines: a. UAZ-450; b. ZIL-130; 1. Without inserts; 2. With inserts.

The State All-Union Research Institute of Tractors tested a D-37M engine incorporating sleeves made from various materials: entirely of grey iron; with high-chromium inserts; with Ni-resist inserts. Quartz dust was fed into the intake manifold of each cylinder. It was established that the wear resistance of cylinders incorporating a Ni-resist insert containing 3.77% chrome was 3 times greater than that of cylinders without inserts, and the wear resistance of cylinders containing high-chrome inserts was 5 times greater (fig. 5).

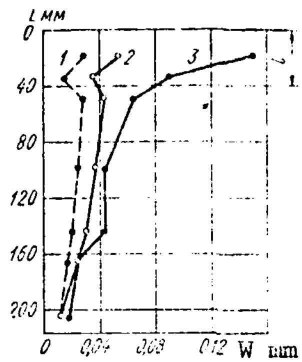


Fig. 5. D-37M engine cylinder wear during an abrasive wear test: 1. Cylinders without inserts, and sleeves with high-chrome inserts; 2. Cylinders and sleeves with Ni-resist inserts; 3. Cylinders with high-chrome inserts, and sleeves without inserts (L is insert length).

The improved abrasion resistance of Ni-resist can apparently be explained as follows. Ni-resist structure contains cement-type carbides alloyed with chrome [$(Fe, Cr)_3C$] having a hardness of 900 to 1,200 kg/$mm^2$ [10]. They are significantly harder than the base (170 to 180 kg/$mm^2$). The presence of hard carbides in a general soft base also causes increased abrasive wear resistance of the Ni-resist. A decrease in chrome content leads to a decrease in the carbide phase and thus decreases the abrasive wear resistance.

According to an experiment conducted by the Gor'kiy Automotive Plant, decreasing the chrome content to 1.4% lowers the Ni-resist wear resistance to such a degree that based on service life it is equivalent to the wear resistance of grey iron [3].

The effect of carbides is also reflected in the nature of the worn surface (fig. 6). As Ni-resist wears, the soft base is abraded first, and the hard carbide inclusions extend beyond the surface which, as a result, becomes rough; this facilitates retention of a large quantity of oil on the surface and is also a reason for the improved wear resistance. Technical specifications for the chemical composition of Ni-resist applicable at the Moscow Automotive Plant imeni Likhachev, Gor'kiy Automotive Plant, and the Automotive Plant imeni Lenin Komsomol stipulate a chrome content between 1.8 and 2.2%. A variation in chrome content even within the tolerances substantially affects the carbide phase content in the structure and consequently the alloy wear resistance. When the chrome content is increased above the norm, the carbide phase content increases sharply (Table 3) and wear decreases. For example, at 2.0 to 2.2% Cr cylinder wear decreases by a factor of 1.4 to 1.6, and at 3.77% it decreases by a factor of 3.

Table 3

Ni-resist carbide phase content and relative abrasive wear resistance at various chrome contents

| Chrome in % | Carbide phase in % | Relative wear resistance* |
|---|---|---|
| 2.0 | 4.3 | 0.89 |
| 2.2 | 7.0 | 0.94 |
| 3.5 | 15.7 | 1.49 |

*Determined on a Kh-4B friction machine at the Institute of the Science of Machines.

There is a particularly large amount of carbide phase (up to 25% at 12 to 15% Cr) in chrome-silicon iron, and cylinder sleeves made from it exhibit high wear resistance during operation. Thus, abrasive wear resistance is determined by the amount of carbides in an alloy, which is primarily associated with chrome content.

In sum, it can be concluded that the wear resistance of cylinders in domestic engines is substantially increased when Ni-resist inserts are introduced. This results from corrosive and, to an even greater extent, abrasive wear resistance. Therefore decreases in cylinder wear can be achieved without introduction of Ni-resist inserts both by effectively protecting the engine from dust and by employing monolithic sleeves made of a material such as chrome-silicon iron, which has especially high abrasive wear resistance.

The decrease in cylinder wear without introduction of Ni-resist inserts by employing effective engine dust protection is corroborated by domestic and foreign engine design practice. For example, data from the Automotive Plant imeni Lenin Komsomol show that cylinders of model 412 engines which do not have inserts exhibit substantially less wear than cylinders of model 408 engines incorporating inserts. During a test of 30 model 412 engines in taxicabs in Tallin, cylinder wear amounted to 0.25 μ/1000 km, while for 403 model engines it was an average of 1.15 μ/1000 km.

The model 412 engine cylinder sleeve design is similar to the sleeve designs of the majority of domestic engines. The chemical compostion of these sleeves differs from that of ordinary grey cast iron employed in blocks and sleeves. However, as the tests in Tallin showed, the wear of ordinary grey iron sleeves did not differ from that of low-alloy cast iron sleeves, and the latter could not therefore be the reason for the low wear of cylinders of the model 412 engines.

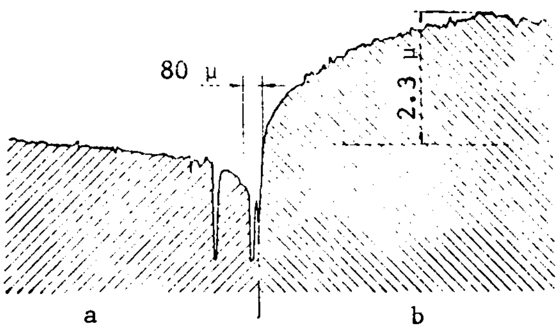


Fig. 6. Profilogram of the working surface of a cylinder sleeve where it joins with the insert in a ZIL-130 engine after 100,000 km (magnified 20,000 times in the vertical direction): a. Grey cast iron; b. Ni-resist.

In contrast to the model 408, the model 412 engines employ a particularly effective dust protection system, which includes air cleaners incorporating paper filters and a full-flow paper fine oil filter.

In summer road tests of ZIL-130 engines use of an improved dust protection system made it possible to decrease wear of cylinder sleeves incorporating Ni-resist inserts by a factor of 2.0 to 2.4 [11].

When engine dust protection is satisfactory, cylinder wear is relatively low, and the difference between cylinders with inserts and those without is negligible. For example, during comparison tests of vehicles on a NAMI cobblestone-road test track, VAZ 2102 engine cylinders without Ni-resist inserts incurred ~11% less wear than engines incorporating inserts. Model 408 engines with Ni-resist inserts in all cylinders exhibited 2.8 to 3.0 times more wear under the same conditions.

For modern engines the increased wear resistance of cylinders incorporating Ni-resist inserts is associated with the abrasive wear resistance of Ni-resist to a significant degree. Cylinder wear can be decreased without introduction of Ni-resist inserts both by efficient engine dust protection and by use of monolithic sleeves constructed of an appropriate material having high abrasive wear resistance. In addition, measures must be employed to decrease corrosive wear by approaching the optimum engine operating temperature and using high-quality fuels and oils.

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