59th ILMENAU SCIENTIFIC COLLOQUIUM
Technische Universität Ilmenau, 11 – 15 September 2017
URN: urn:nbn:de:gbv:ilm1-2017iwk-144:6

HFRR TEST METHOD WITH STAINLESS STEEL SPECIMENS FOR GASOLINE FUELS

Gevorgyan, G., Paukner, R., Erichsen, J., Weisse, M., Dawah, P.

Centre of Competence Analysis, Continental Mechanical Components Germany GmbH
Schorndorfer Str. 91, 93426 Roding, Germany

ABSTRACT

Reducing CO_2 emission is a major challenge for the automotive industry. The different fuels (E10, E100, M15 etc.) that are used for gasoline systems not only influence the CO_2 emission but also significantly influence the friction and wear behavior and subsequently the lifetime of powertrain components. The effect is much higher when biofuels are used. The characterization of tribological properties of gasoline fuels is necessary for a robust design which allows for permanent control of performance.

The High Frequency Reciprocating Rig (HFRR) test concept according to ISO 12156 is the standard test method for evaluating the lubricity of diesel fuels. Up to now, no standard for gasoline fuels is known. The standardized HFRR test method uses 100Cr6 test specimens which are stable in contact with diesel fuel, but, unlike the stainless steel components used in gasoline fuel injection systems, is prone to corrosion in a gasoline environment typically containing a certain amount of water.

This paper aims to develop a lubricity test method with stainless steel for gasoline fuels and reports first results for various fuel compositions.

Index Terms - HFRR, lubricity, wear, friction coefficient, gasoline fuel, stainless steel

1. INTRODUCTION

Further characterization of diesel fuels regarding lubricity, the High Frequency Reciprocating Rig (HFRR) test concept according to ISO 12156 is a well-established method [1]. The standardized HFRR test deals with 100Cr6 test specimens, which is an important material for diesel fuels injector systems. The literature displays many fundamental studies with diesel fuels with standard HFRR test methods and other tribological equipment, in which different parameters as diesel composition, additives, temperature, etc. on the HFRR value were investigated. Not only the ball wear scar diameter (WSD), but also other tribological parameters as ball wear volume, wear of plate and friction coefficient were determined and the wear surfaces as well as the films deposited on the surface were analyzed [2-6].

Increasing costs of crude oil and the demands for CO_2 reduction propels the search for alternative gasoline fuels. For that reason gasoline fuels are blended with alcohol in order to reduce the content of fossile energy. The gasoline fuels’ ingredients define its properties. Blending fuel with alcohol (methanol or ethanol) changes many of its properties, e.g. the lubricity. Basic constituents of gasoline fuels are listed and characterized in the following: paraffins, olefins, naphthenes or cycloparaffins etc. [7].

The tribological properties of gasoline fuels have been investigated by several authors [8-12]. The lubricity of hydrated and anhydrous ethanol gasoline fuel blends was evaluated by means of a standard HFRR tester [10]. Increasing bioethanol content from 10 to 40 v/v % has been reported to reduce friction and wear. For higher bioethanol contents, wear and friction can be considered constant. Higher temperatures can lead to composition changes of the fuels resulting a change in lubricity [12].

2. EXPERIMENTAL

2.1 Test fuel and material

2.1.1 Test fuel

For the tests, different country-specific fuels (E10, E100 and M15) were used. These fuels are test fuels which are used for the validation of the gasoline systems. E10 is a low level blend consisting of 90% gasoline and 10 % ethanol. E100 is a pure ethanol fuel specific for Brasil. It usually consists of 93% ethanol and 7% water and is produced from sugar cane plants. M15 represents the alternative gasoline fuel primarily used in China. M15 is a mixture of 15% methanol and 85% gasoline [13]. The properties of E10, E100 and M15 fuels are shown in Table 1.

Table 1. Properties of test fuels E10, E100 and M15

Property	**Unit**	**E10**	**E100**	**M15**
Density (20°C)	kg/m^3	742,1	808,95	750,3
Initial boiling point (IBP)	°C	37,9	67,8	38,6
Final boiling point (IBP)	°C	195,3	81	192,7
Ignition temperature	°C	-	-	220
Ethanol content (max.)	%	10	93	0
Methanol content	%	0	0	15
Gasoline content	%	90	0	85
Water content	%	< 1	< 7	-
Vapor pressure	kPa	66,7	16,7	80,1

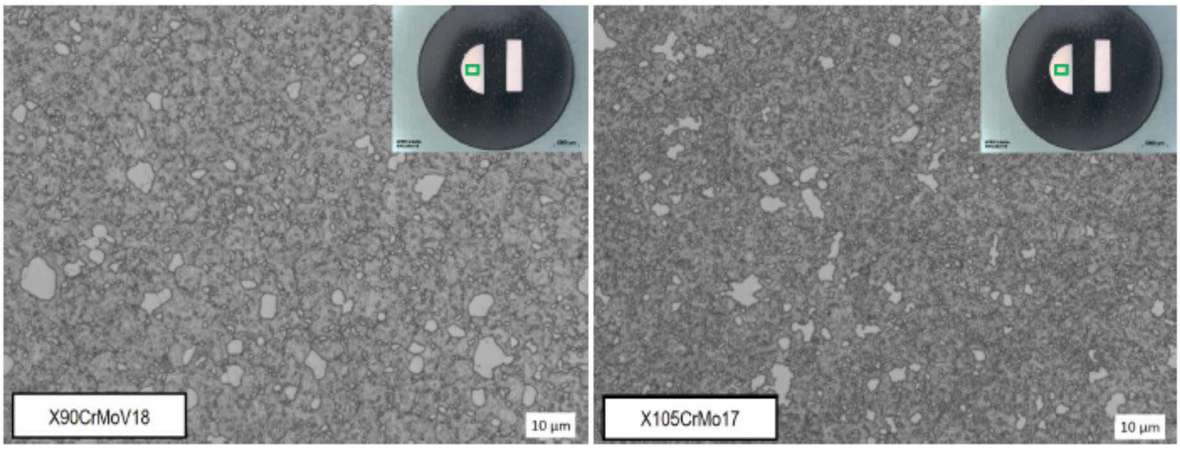
2.1.2 Test material

While the standardized HFRR test uses specimens made of ball-bearing steel 100Cr6 (1.3505, SAE 52100), the disc and ball in our modified equipment are made of stainless steel. The 6 mm balls were made of X47Cr14 (1.3541, AISI 420C) with a hardness of ca. 700 HV and a roughness of Rz < 1µm and the discs (D10 mm x 3 mm) were made of X90CrMoV18 (1.4112, AISI 440B) with ca. 650 HV and Rz < 1µm or X105CrMo17 (1.4125, AISI 440C) with ca. 650HV and Rz < 1µm, respectively. The materials for the HFRR test were chosen according to those typically used in gasoline fuel injection equipment. The chemical composition of the stainless steels used is shown in Table 2.

Table 2. Chemical composition of specimens

Material	C	Si	Mn	P	S	Cr	Mo	V
X47Cr14	0,43-0,50	1,00	≤ 1,00	0,04	≤ 0,030	12,5-14,5	-	-
X90CrMoV18	0,85-0,95	1,00	≤ 1,00	0,04	≤ 0,015	17,0-19,0	0,90-1,30	0,07-0,12
X105CrMo17	0,95-1,20	1,00	≤ 1,00	0,04	≤ 0,015	16,0-18,0	0,40-0,80	-

Microstructural analyses of disc and ball materials were performed. Figures 1 and 2 show their uniform martensitic structure containing coarse primary carbides and finely distributed secondary carbides. X90CrMoV18 forms round primary carbides (Fig. 1, a) whereas X105CrMo17 tends to elongated primary carbides (Fig. 1, b). The orientation is random and the size of the primary carbides for both materials is nearly the same. The microstructure of the investigated ball from X47Cr14 shows a tempered martensitic structure with fine carbides (Fig. 2).



a) X90CrMoV18 b) X105CrMo17

Figure 1. Microstructure of disc materials

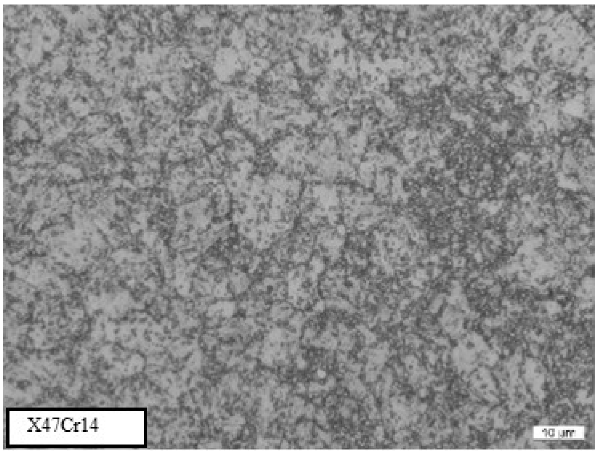


Figure 2. Microstructure of X47Cr14 ball material

2.2 HFRR test method

The lubricity tests were carried out in a High Frequency Reciprocating Rig made by PCS Instruments. A sample of the fluid under test is placed in a test reservoir which is maintained at the specified test temperature. A fixed steel ball is held in a vertically mounted chuck and forced against a horizontally mounted stationary steel plate with an applied load (Fig. 3). The test ball is oscillated at a fixed frequency and stroke length while the interface with the disc is fully immersed in the fluid.

Experience shows that gasoline fuels evaporate partly after standard test conditions, even at room temperature. It was observed that especially E100 shows a very pronounced evaporating behavior. The minimum fuel level guaranteeing the lubrication is already reached after a test period of about 20 minutes, so refilling the reservoir in necessary. After the test the wear scar on the ball is evaluated with optical microscope. The mean wear scar diameter (MWSD), i.e.

the average of its x and y diameters generated on the test ball is taken as a measure of the fluid lubricity (Fig. 4, a).
Tests with different fuel (E10, E100 and M15) at different temperatures (25°C, 50°C and 80°C) were performed (Table 3). The wear were analyzed using 3D optical equipment of NanoFocus (Fig. 4, b). The friction coefficient was permanently recorded during the measurement.

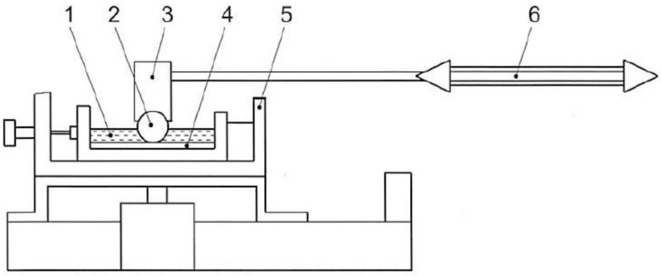
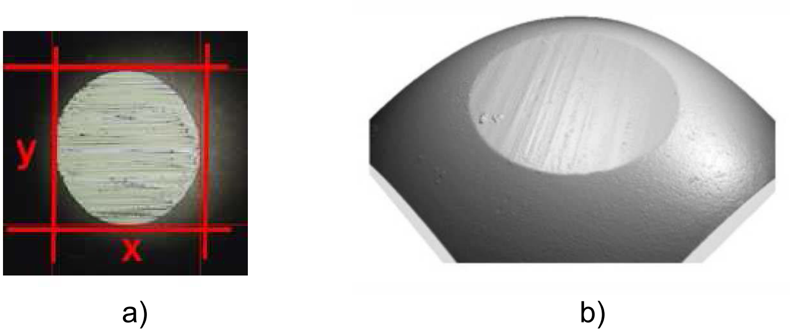


Figure 3. Experimental device for the HFRR test: 1) fluid reservoir 2) test ball 3) test mass 4) test disc 5) heating bath 6) oscillating motion.



a) b)

Figure 4. Wear scar on ball: a) optical microscopy and b) 3D measurement

Table 3. Standardized HFRR test conditions for diesel fuels and new test conditions for gasoline

Parameter	Unit	HFRR standard test for diesel	new test for gasoline
		Value	Value
Fluid volume	ml	2 +/-0,2	15 +/-0,2
Stroke length	mm	1 +/-0,02	1 +/-0,02
Frequency	Hz	50 +/-1	50 +/-1
Fluid temperature	°C	60 +/-2	25, 50, 80 +/-2
Test mass	g	200 +/-1	200 +/-1
Test duration	min	75 +/-0,1	20 +/-0,1

3. RESULTS AND DISCUSSION

3.1 Wear analysis

3.1.1 MWSD wear

In Figure 5 the mean wear scar diameter (MWSD) of the tests with E10, E100 and M15 at different temperatures with disc materials X90CrMoV18 and X105CrMo17 are shown. The MWSD on the X47Cr14 ball for fuels E10 and M15 and disc material X90CrMoV18 decreases with increasing temperature. The HFRR value of the E10 fuel at 50°C is ca. 25% lower than that at 25 °C. This is caused by the evaporation of some of the fuel components and therefore the change of the fuel composition. The MWSD value of the E100 and X90CrMoV18 at 50°C increases ca. 12% and at 80°C no significant increase of MWSD is observed. The MWSD of fuel E100 at 50°C with material X90CrMoV18 in comparison with E10 and M15 shows a ca. 70% higher value. The tests with X105CrMo17 show that the MWSD value of the fuels E10 and E100 rises when increasing the temperature from 25°C to 50°C, while the MWSD of fuel M15 with material X105CrMo17 decreases from 50°C to 80°C. The standard deviation for M15 is lower. The material does not seem to have a considerable influence on the MWSD but there is a slight tendency of higher results for X105CrMo17.

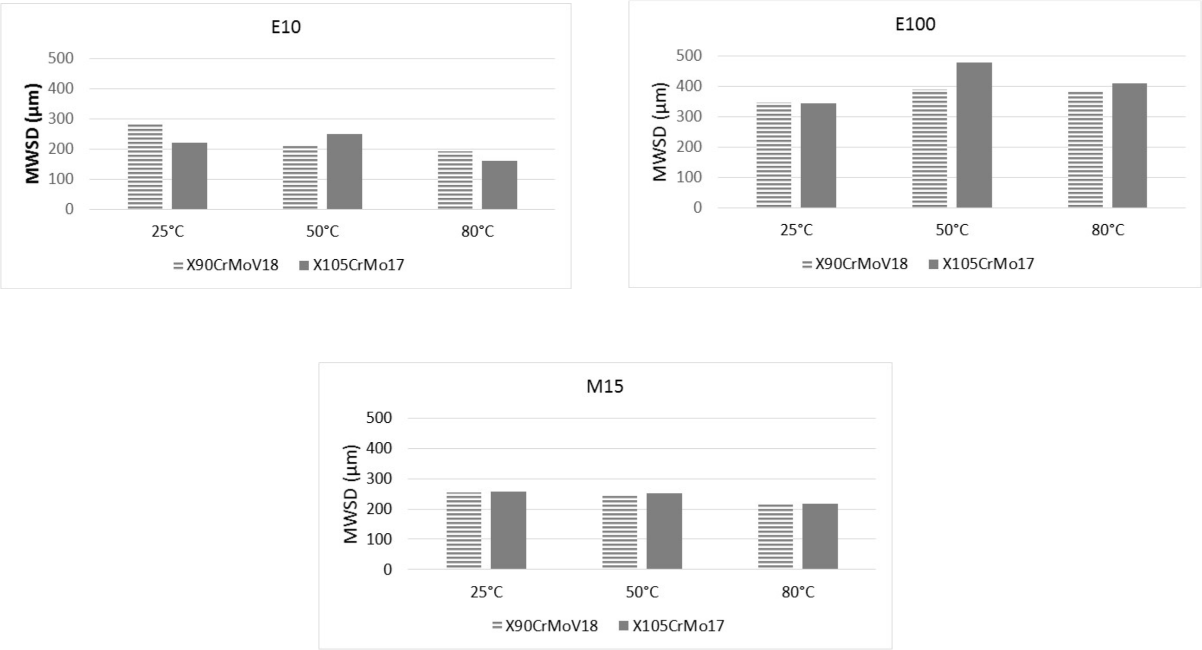


Figure 5. Mean wear scar diameter (MWSD) depending on the different fuels, materials and temperature

3.2 Friction coefficient

Figure 6 shows the development of the friction coefficient over test time for E10, M15 and E100 with X90CrMoV18 disc material at 80°C. While E10 and M15 have a very short run-in phase of about ca. 50 seconds and a low stationary value of μ = ca. 0,2, the run-in phase of E100 is more pronounced and lasts longer (ca. 180 seconds) and the stationary value μ = ca. 0,4 is twice as high.

The friction coefficient of E10 and M15 with different disc materials at different temperatures is displayed in Figure 7. In the diagram, the average friction coefficient after the run-in phase is summarized. E10, E100 and M15 show different friction coefficients.

The general tendency of E10 and M15 is a decreasing friction coefficient with increasing temperature, while with E100 the friction coefficient increases.

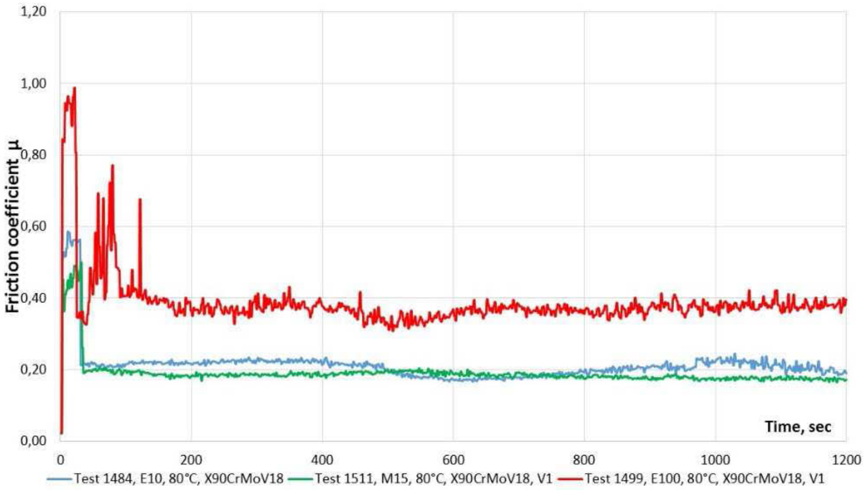


Figure 6. Friction coefficient of E10, E100, M15 at 80°C and with X90CrMoV18 material.

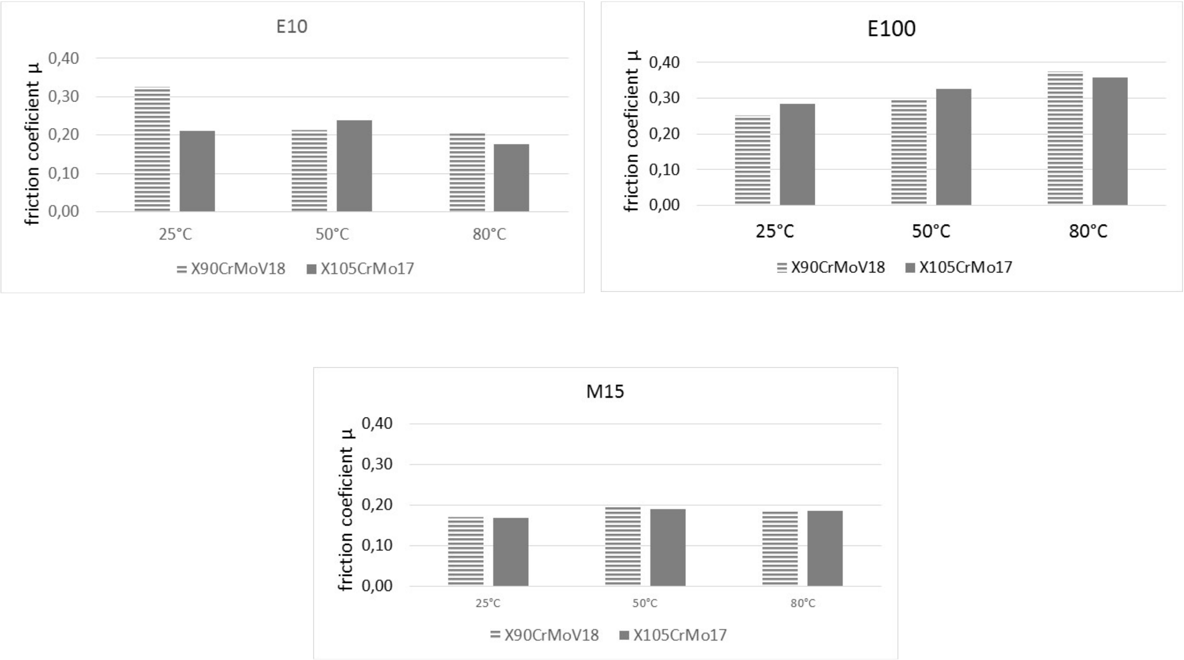
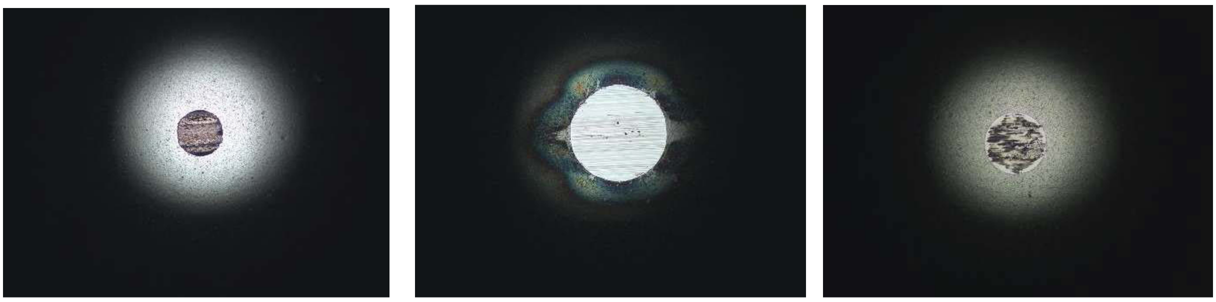


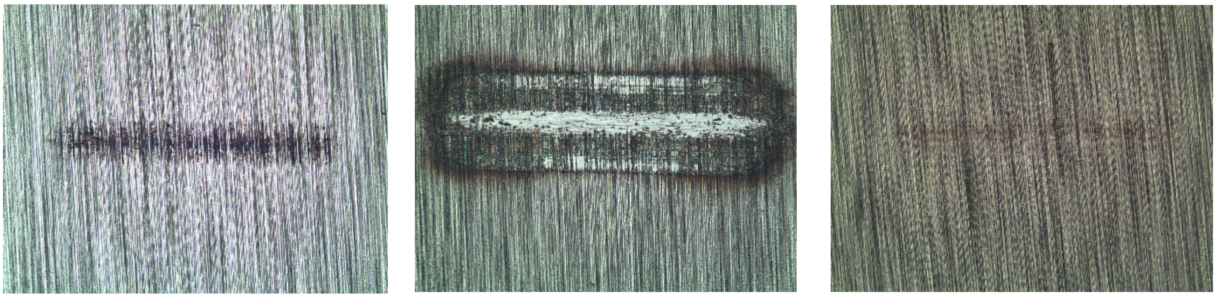
Figure 7. Friction coefficient depending on different fuels, materials and temperature

3.3 Wear surface

The wear marks on the X47Cr14 balls show a distinct tribofilm at all test conditions except for E100 at higher temperature (Fig. 8). Only with E100, the film on the disc is partially oxidic. Abrasive wear scars on the ball are observed with disc material X90CrMoV8 at 80°C and with disc material X105CrMo17 at 50°C and 80°C. This difference between the two materials is due to the higher carbide content of X105CrMo17. The MWSD, friction coefficient and wear surfaces of ball are summarized in Table 4.



E10, 80°C, X90CrMoV8, ball E100, 80°C, X90CrMoV8, ball M15, 80°C, X90CrMoV8, ball



E10, 80°C, X90CrMoV8, disc E100, 80°C, X90CrMoV8, disc M15, 80°C, X90CrMoV8, disc

Figure 8. Wear surfaces of ball and disc with fuels E10, E100 and M15 at 80°C and with material X90CrMoV8

Table 4. Results of MWSD, friction coefficient and wear surfaces of ball

	Ball	X47Cr14					
	Disc	X90CrMoV18			X105CrMo17		
		25 °C	50 °C	80 °C	25 °C	50 °C	80 °C
E10	MWSD / µm	283	214	192	222	249	161
	µ	0.32	0.21	0,21	0.21	0.24	0.18
	tribofilm	yes	yes	yes	yes	yes	yes
E100	MWSD / µm	347	389	388	345	478	411
	µ	0.25	0.29	0.38	0.28	0.33	0.36
	tribofilm	yes, ox.	yes, ox.	no	yes, ox.	yes, ox.	no
M15	MWSD / µm	253	244	218	259	251	218
	µ	0.18	0.19	0.19	0.17	0.19	0.19
	tribofilm	yes	yes	yes	yes	yes	yes

4. CONCLUSIONS

This paper aims to establish a lubricity test method for gasoline fuels using a modified HFRR tester and reports first results for various fuel compositions. Specific features of this test are, first of all, the substitution of 100Cr6 ball bearing steel by different stainless grades for the ball and the disc to prevent corrosion effects that would affect the lubricity results and, secondly, a significantly reduced test duration to account for the evaporation of gasoline fuels, especially at high temperatures. In order to gain useful tribological information, these stainless grades were chosen according to the ones typically used in gasoline fuels injector systems.

The tests were conducted with country-specific fuel blends E10, E100 and M15 at 25 °C, 50 °C and 80 °C.

The results are summarized in Table 4. The most interesting findings are:

- The HFRR value (in terms of the mean wear scar diameter MWSD) of the E10 fuel decreases by ca. 25% when rising the temperature from 25 °C to 50 °C. In comparison with E10 and M15, the MWSD of fuel E100 shows a ca. 70% higher value at 50 °C with material X90CrMoV18.
- The general tendency of E10 and M15 is a decreasing friction coefficient with increasing temperature, while with E100 the friction coefficient increases. E10 and M15 have a very short run-in phase and a low stationary friction coefficient μ = ca. 0,2, while the run-in phase of E100 is more pronounced and lasts longer and the stationary value μ = ca. 0,4 is twice as high.
- The surfaces of the discs tested with E100 show partial oxidation, with the fuels E10 and M15 an oxidation-free tribofilm is formed. At high temperatures, the surface of the ball tested with E100 shows strong abrasive wear, whereas the wear surfaces of the balls tested with fuels E10 and M15 show mainly tribofilm. At 25°C and 50 °C the balls of the E10 and M15 tests show light abrasive marks.

The main cause of the bad lubricity and high abrasive wear of E100 at high temperatures is the water content. The water leads to a corrosive attack of the tribo-surfaces which promotes abrasive wear. The vapor pressure properties of the fuels probably have an influence on the wear behavior.

Ball and disc material does not seem to have a considerable influence on the MWSD but there is a slight tendency of higher wear with X105CrMo17, as it has a higher carbide content.

However, final conclusions for characterization of wear and friction in gasoline fuels can be drawn only after a thorough examination of tribological processes at various temperatures. Moreover, the lubricity of gasoline fuels must be checked at temperatures which are typical for gasoline injection systems. This is the focus of current research.

REFERENCES

[1] Diesel fuel – Assessment of lubricity using the high-frequency reciprocating rig. Part 1: Test method (ISO 12156-1, 1997)
[2] G. Knothe, and K.R. Steidley, Lubricity of components of biodiesel and petrodiesel. The origin of biodiesel lubricity, Energy & Fuels, pp. 1192-1200, 19/2005
[3] D.P. Wei, and H.A. Spikes, The lubricity of diesel fuel, Wear, pp. 217-235, 111/1986
[4] M. Nikanjam, and P.T. Henderson, Lubricity of low sulfur diesel fuels, SAE technical Paper. Warrendale, U.S., pp. 743-760, 1994
[5] P.I. Lacey, and B.D. Shaver, Evaluation of the wear mechanisms present in the HFRR fuel lubricity test. Proceedings of the 2nd Int. Colloquium on Fuels, pp. 199-210, 1999
[6] H. Hunger, U. Litzow, S. Genze, N. Dörr, D. Karner and C. Eisenmenger-Sittner, Tribological characterisation and surface analysis of diesel lubricated sliding contacts, Tribologie und Schmierungstechnik, pp. 6-13, 6/2010
[7] R. Konrad, Ottomotor-Management. Springer Fachmedien Wiesbaden, 2014
[8] D.P. Wei, H.A. Spikes, and S. Korcek, The lubricity of gasoline, Tribology Transactions, pp. 813-823, 4/1999
[9] P. Arkoudeas, D. Karonis, F. Zannikos, and E. Lois, Lubricity assessment of gasoline fuels, Fuel Processing Technology, pp. 107-119, 122/2014
[10] J. Agudelo, A. Delgado, and P. Benjumea, The lubricity of ethanol-gasoline fuel blends, Rev. Fac. Ing. Univ. Antioquia, pp. 9-16, 58/2011
[11] I.M. Sivebaek, and J. Jakobsen, The lubricity of ethers and alcohol-water blends, NT2014-120, pp. 1-6
[12] H. Hunger, N. Dörr, U. Litzow, A. Orfaniotis, B. Raether, and N. Kashani, Influence of the ethanol content on the oscillating sliding contact, Proceedings of the 18th International Tribology Colloquium, TAE, Ostfildern, p. 136, 2012
[13] M. Bertau, H. Offermanns, et al., Methanol: The Basic Chemical and Energy Feedstock of the Future, Springer Berlin Heidelberg, 2014

CONTACTS

Gevorg Gevorgyan	gevorg.gevorgyan@continental-corporation.com
Jörn Erichsen	joern.erichsen@continental-corporation.com
Manfred Weisse	manfred.weisse@continental-corporation.com
Patrick Dawah	alain.patrick.dawah.tankeu@continental-corporation.com

Centre of Competence Analysis (CCA)
Validation & Analysis of Mechanical Systems
Continental Mechanical Components Germany GmbH
Schorndorfer Str. 91, D-93426 Roding, Germany