EFFECT OF MOLYBDENUM DISULFIDE AND OPEN POROSITY ON DURABILITY OF SINTERED VALVE SEATS IN COMBUSTION ENGINES FUELLED WITH COMPRESSED NATURAL GAS

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Abstract

Valve-seats are the most thermally and mechanically loaded components of combustion engines. These loads increase rapidly with the use of LPG and CNG gaseous fuels. Conducted at BOSMAL Automotive Research & Development Institute numerous durability tests of self - and spark ignition combustion engines proved, that the temperature of diesel, gasoline, LPG and CNG exhaust gases measured in the exhaust manifold reaches in case of CNG around 1223 K. The valve seats fueled with LPG are usually manufactured from high-alloyed sintered powders. Attempts of application of same valve seats to the engines fueled with CNG (as engines fueled with LPG) were finished unsuccessfully. The aim of the study was to investigate the effect of molybdenum disulfide and open porosity saturated with Cu on the durability of the valve seat faces in the operating conditions of two-cylinder engine type 0.9 SGE TC80 CNG fueled with natural gas. Durability test was conducted according to the methodology of BOSMAL procedure. There were measuring (among others parameters) the power, torque and rotation speed, also the exhaust gases temperature and the hourly fuel consumption. Studies had shown a strong influence of molybdenum disulfide and open porosity on the durability of tested valve seats in engine fueled with compressed natural gas (CNG).

Keywords: Sintered valve seat, combustion engine, CNG

1. INTRODUCTION

Exhaust seats and valves decides about the constructional plasticity high-temperature creep resistance, i.e. simultaneous resistance of the material to mechanical deformation at elevated and high temperatures, and also the resistance of valve seat faces to the corrosive influence of the hot exhaust gases [1, 2]. Conducted at BOSMAL Automotive Research & Development Institute numerous durability tests of self - and spark ignition combustion engines showed, that the temperature of diesel, gasoline, LPG and CNG exhaust gases measured in the exhaust manifold reaches respectively around 1023 K, 1073 K, 1123 K and 1223 K [3]. In order to assure a sufficiently high creep resistance and resistance to oxidizing influence of hot exhaust gases exhaust valve faces regardless of used fuel are fused with thin stellite layers [4, 5] with average chemical composition given in the **Table 1**.

Table 1 Average chemical composition of stellite used for the exhaust valves faces in diesel, gasoline, LPG and CNG fueled engines

Material	Average chemical composition, wt. %				
	C	Cr	Ni	W	Co
Stellite 7 F	2.0	25.0	22.0	1.2	49.8

In contrast to the exhaust valves, exhaust valve seat faces of diesel and gasoline fueled engines, where exhaust gases temperature reaches ca 1073 K [6, 7], usually are made of high-alloyed steel or alloy cast, while in highly thermally and mechanically loaded engines fueled with gasoline and LPG gas (where temperature of exhaust gases reaches ca 1123 K [8], valve seats are made of high-alloyed sintered powders (**Table 2**).

Table 2 Average chemical composition of sintered powder aimed for production of valve seats used in engine fueled with gasoline and LPG gas

Mater.	**Average chemical composition, wt. %**												
	C	Cr	Ni	W	Al	V	Mo	Mn	Cu	Si	P	S	Fe
Sinter	0.74	4.0	0.14	3.5	0.32	2.0	8.2	0.49	16.7	0.71	< 0.01	0.18	Bal.

Attempts to power with CNG natural gas the engines adapted to LPG gas have been finished unsuccessfully. After approx. 40 hours of engine run during durability stand test at temperature 1223 K was stated simultaneous, increasing with time, deformation of sintered valve seat faces and intensive reduction of molybdenum disulfide in the sinter. In this paper the improvement of valve seat faces durability was investigated in the operating conditions of two-cylinder engine powered with natural gas. Durability test was conducted on durability engine test stand in BOSMAL A R & D Institute.

2. THE RESEARCH MATERIALS

Tests of molybdenum disulfide addition and open porosity effect on durability of valve seats in engines fueled with natural gas were accomplished with using two batches of valve seats which were pressed, sintered and fused with Cu and with an alloy with slightly higher melting temperature i.e. Cu-Ni with chemical composition given in the **Table 3.**

Table 3 Chemical composition of sintered valve seats used in experimental engine fueled with CNG

Content of MoS_2 in sinter Batches		**Chemical composition, wt. %**													
		C	Cr	W	V	Mo	Co	Cu	Si	Al	Mn	Ni	P	S	Fe
I	initial	1.6	3.2	6.0	5.1	5.8	9.0	16.8	0.34	0.21	0.07	0.23	0.11	0.012	Balance
II	higher	1.0	4.2	4.5	1.5	8.4	16.2	20.3	0.85	0.25	0.54	0.29	0.13	0.088	Balance

Table 4 Density, relative and open porosity of tested valve seats

Batch I, sinter with initial content of MoS_2					**Batch II, sinter with higher content of MoS_2**				
Valve seat No.	**Density g / cm^3**	**Relative porosity %**	**Open porosity %**	**Bonded flux**	**Valve seat No.**	**Density g / cm^3**	**Relative porosity %**	**Open porosity %**	**Bonded flux**
1	7.83	97.9	2.1	Cu	1	6.4	79.5	20.5	Cu-Ni
2	7.86	98.2	1.8	Cu	2	6.4	80.3	19.7	Cu
3	7.92	98.8	1.2	Cu	3	6.6	83.1	16.9	Cu
4	7.97	99.3	0.7	Cu	4	7.0	87.4	12.6	Cu

Analysis of density, relative and open porosity of tested valve seats with decreased molybdenum disulfide content (Batch I) and with increased disulfide molybdenum content (Batch II) revealed, that with average density of sinters from Batch I ca 7.90 g / cm^3 relative porosity of these sinters was increasing from ca 97.9 % to ca 99.3 % and open porosity was increasing from around 0.7 % to ca 2.1 %. Sinters from Batch II with average density ca 6.60 g / cm^3 relative porosity was increasing from ca 79.5 % to ca 87.4 % while open porosity of these sinters was increasing from ca 12.6 % to 20.5 % (**Table 4**).

Metallographic analysis of valve seats from Batch I and Batch II showed on the contrary corresponding to the density of sinters many saturated Cu or Cu-Ni open pores and fine, with high dispersion carbide precipitations of W, Mo and V (**Figure 1**).

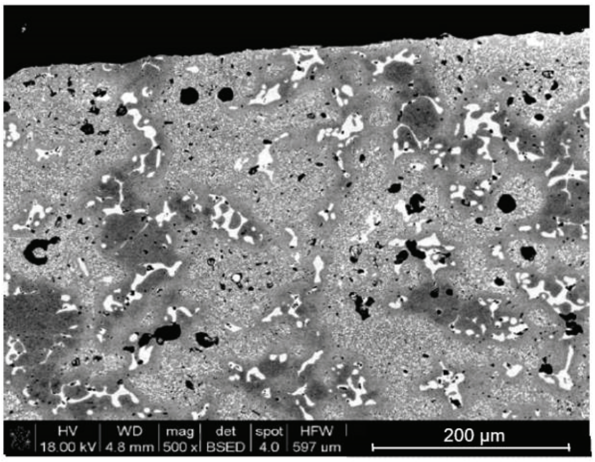
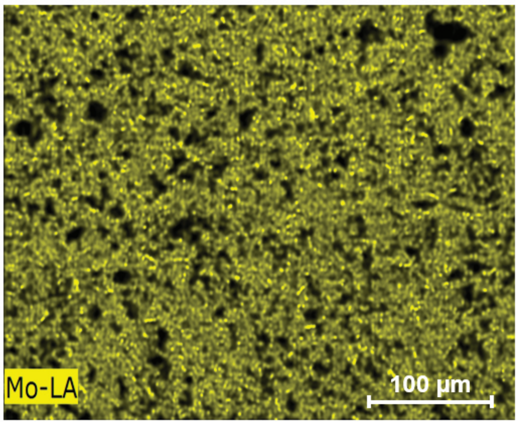


Figure 1 Sintered valve seats structure, seat No. 2, Batch II, Table 4. White, branched saturated with Cu open pores, many fine carbides of W, V and Mo, and few black closed pores are visible

Moreover in **Figure 2a** and **2b** can be seen uniform distribution of molybdenum and sulfur revealed by means of scanning electron microscope (SEM) on exhaust valve seat metallographic section.



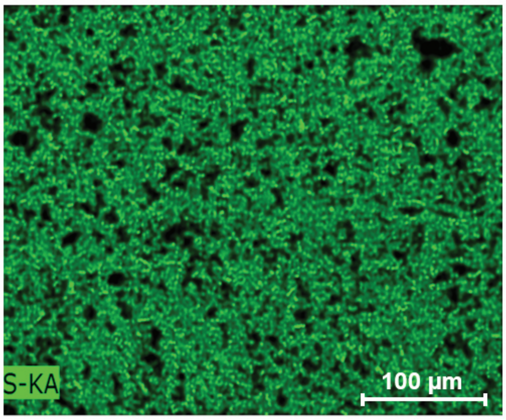
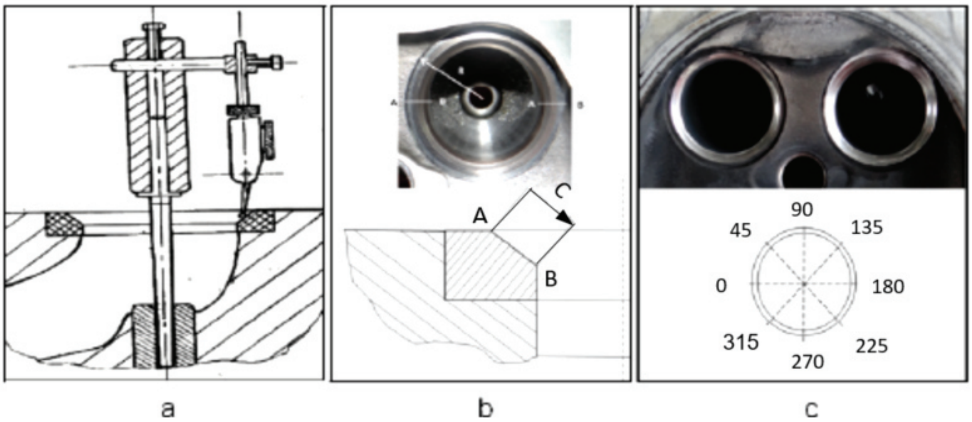


Figure 2a Distribution of molybdenum **Figure 2b** Distribution of sulfur
on section of exhaust seat from Batch II, No. 2 with higher MoS_2 content

3. MATERIAL AND RESEARCH METHOLOGY

For the examinations of sintered valve seats, two batches of valve seat material (i.e. with lower and higher molybdenum disulfide content and fused with Cu and with an alloy with higher melting temperature) were used. The properties of tested sintered valve seats are given in **Table 4**. Before testing these valve exhaust seats were preliminarily machined, marked and mounted on the engine head. After assembly of the valve seats their raw rings were turned and ground, next the seat faces of the valves were ground together with the corresponding exhaust seat faces. Hundred hours of durability testing of seat faces were performed on a two-cylinder engine (type 0.9 SGE TC80 CNG) fueled with natural gas. The durability test was conducted on a test stand according to the BOSMAL “Process Verification Procedure” methodology, measuring (among other parameters) the power, torque and rotation speed, also the exhaust gases temperature and the hourly fuel consumption. During the durability tests periodic endoscopic observations of the seat faces and the valve surfacesand their corresponding exhaust valve faces were also performed. To track wearability, the drift of roundness and width of seat faces (circumference) after 100 hours of engine test in relation to measurements of base profile of valve seats was analyzed (**Figures 3a, b, c**).



Figures 3a, b and c Measurement of wear of active seat face surface after 100 hours durability engine test on engine test stand: a - measurement of drift roundness of seat face in relation to the reference surface; b - measurement of width of seat face, where: A - B - measured width points, C - direction of measurement, c - measurement every 45^0 on circumference of seat face

4. TEST RESULTS AND DISCUSSION

As a result of the 100 hours durability test performed for examined seats, the drifts of roundness and width of seats from Batch I, No. 1…4, with suitable open porosity 2.1 %, 1.8 %, 1.2 % and 0.7 % are given in **Figures 4** and **5**.

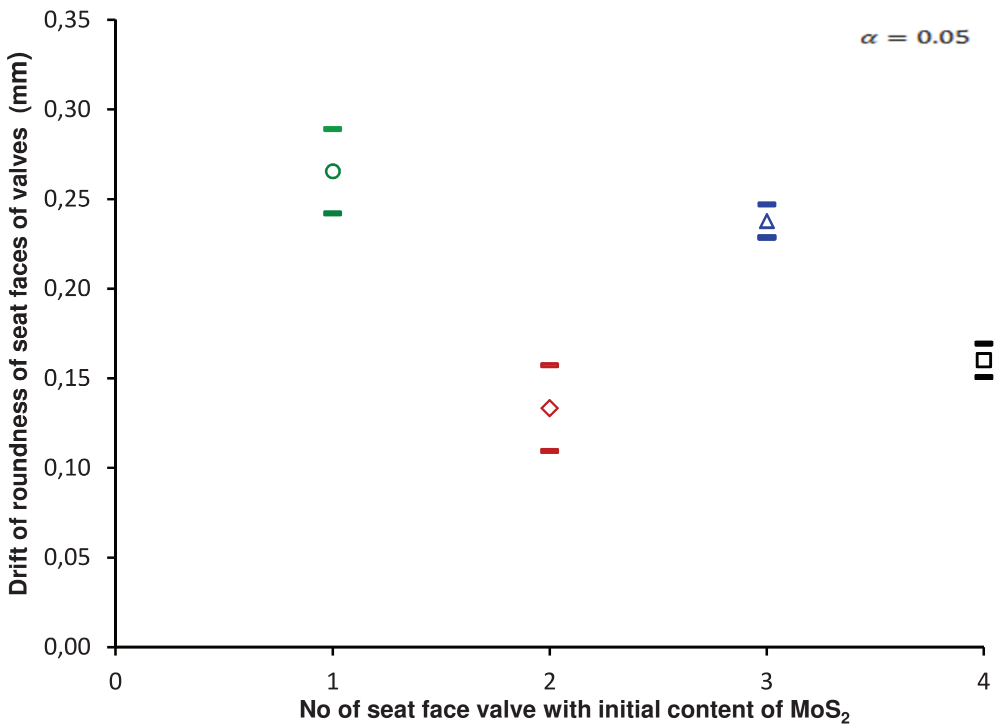


Figure 4 The drifts of seat faces roundness from Batch I, No. 1…4, in relation to measurements of their base profiles after 100 hours durability engine test, fueled with CNG

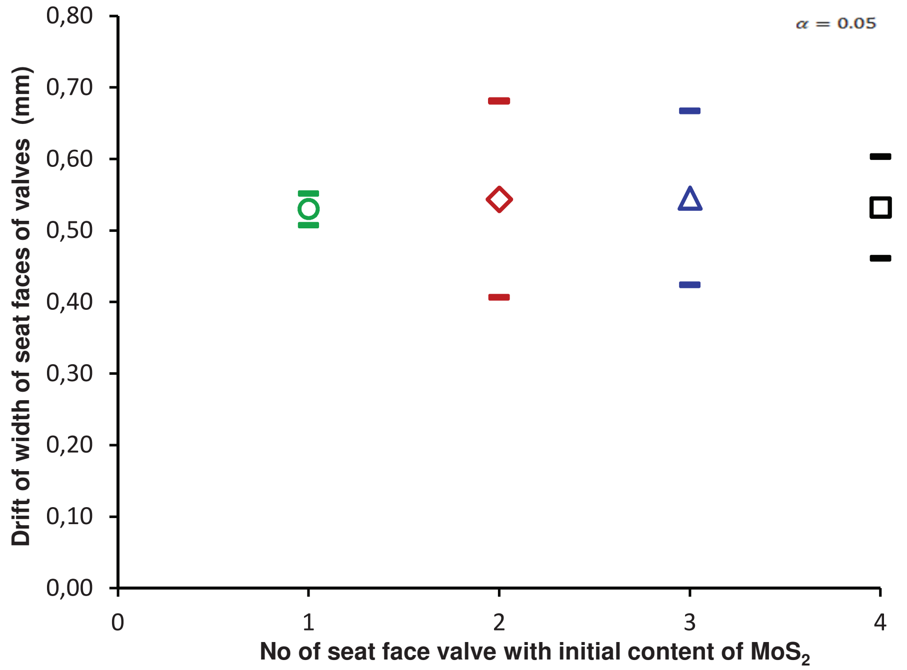


Figure 5 The drifts of seat faces width from Batch I, No. 1 … 4 in relation to measurements of their base profiles after 100 hours durability engine test fueled, with CNG

Whereas drifts of roundness and width of active surfaces of valve seat faces from Batch II No. 1 … 4 with suitable open porosity 20.5 %, 19.7 %, 16.9 % and 12.6 % with higher content of molybdenum disulfide are given in **Figures 6** and **7**.

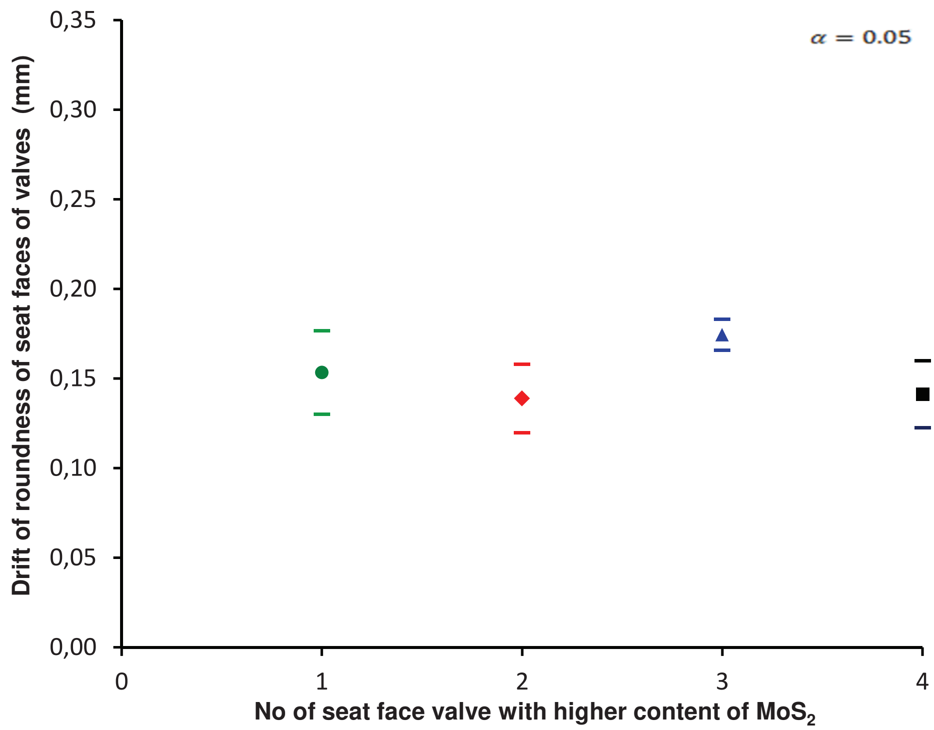


Figure 6 The drifts of seat faces roundness from Batch II, No. 1…4, in relation to measurements of their base profiles after 100 hours durability engine test, fueled with CNG

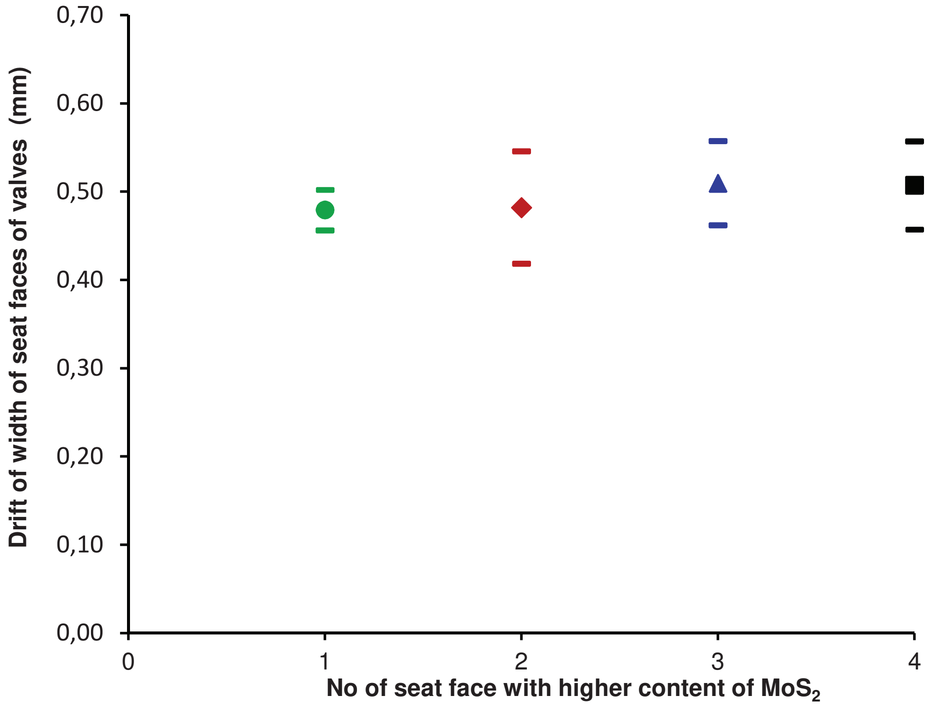


Figure 7 The drifts of seat faces width from Batch II, No. 1…4, in relation to measurements of their base profiles after 100 hours durability engine test, fueled with CNG

5. CONCLUSION

Based on the 100 hours durability tests performed on a two-cylinder engine (type 0.9 SGE TC80 CNG) it can be stated that the sintered valves seat faces followed by increasing percentage volume of open porosity and molybdenum disulfide content, cause decreasing of roundness drift (**Figure 4** against **Figure 6**) and decreasing of width drift (**Figure 5** against **Figure 7**), i.e. better resistance to deformation of the seat faces active surface in the environment of exhaust gases from engines fueled with natural gas (CNG).

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