DEVELOPMENT OF HIGH STRENGTH GRAPHITE FOR USE IN HEAVILY LOADED SYSTEMS

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Introduction

Self sintering mesocarbon microbeads and bulk mesophase in general are raw materials suitable for production of fine grained isotropic carbon materials exhibiting excellent strength and high density without using an additional binder. The paper deals with the development of such high strength graphites suitable for applications under severe conditions such as pistons in fired engines and sealing rings in heavily loaded systems.

The influence of various processing on the properties and the benefits for different applications are reported.

Experimental

Five different commercially available powders based on petroleum residues as well as on coal tar have been investigated. After grinding and screening to appropriate grain size distributions, samples of 5 x 5 x 5 mm were used to study the expansion/shrinkage behaviour and the weightloss up to 1000 °C. Samples of 120 x 70 x 20 mm were used to determine the physical properties after heat treatment up to 1000 °C with average heating rates ranging from 0.5 °C to 15 °C per hour. Finally, the materials were isostatically molded with sizes up to ∅ 150 x 300 mm and 160 x 160 x 600 mm, respectively. The carbonization cycles were adapted to the individual behaviour of the different starting materials. Final graphitization was performed between 2100 °C and 3000 °C in industrial production units. The resulting blanks were machined and tested as pistons in two stroke and four stroke engines and in different types of sealings.

Results and discussion

The typical chemical properties of the investigated powders and the physical properties after baking to 1000 °C using a cycle with a mean heating rate of 5 °C/h are summarized in table 1. Despite the differences in the chemical composition and nature of the starting raw materials (e. g. VM, O, S), all materials exhibit high strength after baking, whereas the petroleum based materials D and E are characterized by higher shrinkage and significantly high open porosity.

The adaption of expansion/shrinkage behaviour, weight loss during carbonization and variation of the critical heating rate with molded density and block size was performed as described in detail elsewhere [1]. Table 2 summarizes the physical properties that can be achieved using such individually adapted process parameters ranging from 4 weeks baking time in case of material E to 8 weeks, necessary for sample C to avoid cracking or bloating. The temperature raise during graphitization had to be limited to 60 °C/h in all cases.

Material C exhibits the highest strength but also increased brittleness. This can be assigned to the high oxygen content of the raw material leading to poor graphitizability, clearly expressed in low thermal conductivity and high Young's modulus.

Whereas the materials A to E in table 1 can be used as pistons in fired engines of automobiles or other motors for the application in sealing technology, especially the tribological behaviour is not satisfying. This lack can be improved by doping the basic graphites with ceramic additives like SiC or B_4C. In that case, that max. HTT has to be limited to about 2100 °C, as done in case of material Ad.

Tests as sealing rings in high pressure and high speed applications exhibit that the doped mesophase can be an alternative material to commercial resin- and metal impregnated grades but optimization of design and counter materials is necessary.

The test as piston in chain saw engines reveal the following advantages:

- Power increase: 3 % - 10 %
- Reduction of fuel consumption: 5 % - 8 %
- Reduction of oil consumption: 25 % - 45 %
- Reduction of CH- and CO-emissions: 15 % - 55 %

Ongoing tests in automobile diesel engines prove similar environmental benefits and the increase in combustion efficiency.

Conclusions

Several high strength fine grained graphites based on self sintering raw material are available in commercial amounts and sizes. By individual optimization of the processing, the special demands in different applications under severe conditions can be adapted.

Acknowledgment

The development has been funded by the European Community under grant-no. BRE2. CT94. 0901 and the German Ministry of Education and Research under grant-no. 03M 1065.

References

1. R. Wolf, R. Sperling and W. Huettner, in Ext. Abstr., Carbon 92, 1992, pp. 964.

Raw material		A	B	C	D	E
QI	(%)	94	92	60	84	75
TI	(%)	97	95	95	95	80
Volatile Matter	(%)	13.5	9.5	12.5	14.5	20.5
C	(%)	92	94	89	89	92
H	(%)	3.4	3.1	3.2	4.1	4.1
N	(%)	1.5	1.2	1.2	1.2	1.5
S	(%)	0.4	0.3	0.5	0.15	1.4
O	(%)	1.5	0.7	4.8	1.5	0.7
He-density	($g \cdot cm^{-3}$)	1.40	1.44	1.43	1.31	1.35
Mean grain size	(μm)	15	8	7	30	8
Baked samples						
Bulk density	($g \cdot cm^{-3}$)	1.72	1.70	1.68	1.63	1.75
Porosity	(%)	8	6	5	17	10
Bending strength	(MPa)	105	88	120	98	95
Shrinkage	(%)	11.5	10.5	11.5	13.5	15.5
Mean grain size	(μm)	8	6	5	4	3

Table 1: Typical properties of investigated self sintering powders (A, B, C: coal tar based; D, E: petroleum based) and physical properties of samples 120 x 70 x 20 mm after baking to 1000 °C (mean heating rate: 5 °C/h)

Raw material		A	B	C	D	E	Ad
Bulk density	($g \cdot cm^{-3}$)	2.02	2.0	1.90	1.90	1.90	1.96
Porosity	(%)	4	6	5	10	10	4
Bending strength	(MPa)	145	125	155	120	135	125
Young's modulus	(GPa)	15	15	19	14	15	22
Hardness Shore		95	95	100	80	70	95
Spec. electr. resistance	($\mu\Omega m$)	19	12	28	18	18	10
Thermal conductivity	($Wm^{-1}K^{-1}$)	65	85	40	65	60	45
CTE to 450 °C	($10^{-6}K^{-1}$)	6.9	6.3	5.2	5.5	7.0	6.3

Table 2: Physical properties of samples, ∅ 80 x 100 mm using individually optimized baking and graphitizing cycles (final HTT: A to E: 2450 °C; Ad = 2100 °C; B_4C-doped)