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Hydrodynamic Compaction and Sintering of Titanium Filters

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Abstract. This paper describes the development of an equipment for hydrodynamic compaction for production of porous permeable materials and compares the process with the more widely known hydrostatic process. Technical design data, mathematical expressions involved, effect of operating parameters on quality of the sintered product have been discussed.

Production of porous permeable materials is an exclusive advantage of powder metallurgy. Porous permeable materials have certain merits compared to paper, glass and ceramics. The porous materials are strong, corrosion-resistant and can operate in a wide range of temperature. They undergo mechanical treatment as well as welding easily and are amenable to repeated use.

Research done in the Byelorussian Powder Metallurgy Association resulted in developing an equipment for hydrodynamic compaction of powder materials using gun powder combustion energy. In some cases this equipment successfully competes with the hydrostatic compacting equipment, the advantages of which are widely known.

Such power equipment is based on the principle of gun powder combustion in a closed volume, to create high pressure during compaction of powder materials in a liquid. The first known unit of this type was described in 1952[1,2]. A unit made from a charging chamber of 14-inch naval gun of 480 mm inner diameter and 800 mm length was used for compaction of titanium carbide powders, with nickel as a bonding material, in rubber capsules. To seal the working chamber, gun breech-block was used. A more advanced unit for compaction of powder materials in a liquid with gun powder as energy carrier[3] was developed by McKennon, Radmont and Smith in 1947 and patented in USA in 1953. The sixties were the years when experimental hydrodynamic compacting units[4-7] were developed. Studies made with their help provided us with important experimental material, the analysis of which enabled us to create frame-type hydrodynamic equipment combining the advantages of impulse and isostatic powder compacting methods. A hydrodynamic machine, the power frame and the container of which are wired previously with a strained belt of high strength, enables easy machanisation of the working cycle, increase of capacity and provides both reliability and operation safety.

The diagram of a hydrodynamic frame-type machine is presented in Fig. 1. The machine consists of 2 working containers (No. 3 in Fig. 1) moved by a hydrocylinder

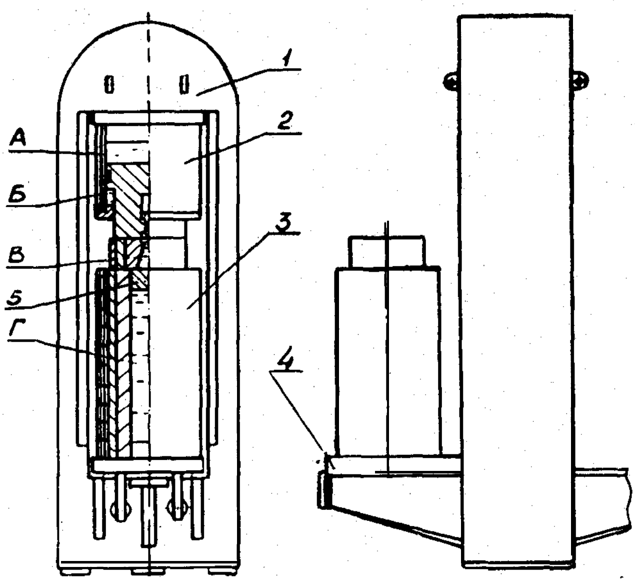

Figure 1. Frame-type hydrodynamic machine.

together with the table (4) and coming in turn into the frame (1) under axial loading. mhere are explosive chambers (marked as B in Fig I), in each of which there is situated a sleeve with a gun powder charge and a capsule. -A moving piston (5) transmits pressure onto the working liquid. Gun powder burning is provided for by combustion of the capsule with the help of a firing pin having an electric-magnetic drive,

Technical data of hydrodynamic machine 6-190/700 are presented below:

1.	Energy carrier	gun powder
2.	Maximum pressure in the working container, MPa	600
3.	Inner diameter of the container, mm	190

4. Height, mm	1055
5. Maximum dimensions of the billet to be compacted :	
diameter, mm	185
height, mm	700
6. Number of containers	2
7. Overall dimensions of the machine : A x B, mm	2830 x 1200
height, mm	3585
8. Duration of the working cycle, min	4
9. Machine weight, kg	11000

The manufacture of tube-type filtering elements is one of the prospective uses of hydrodynamic compaction.

It is possible to numerically predict the hydrodynamic compaction of porous permeable materials. Methods have been developed to determine the billet porosity change; pressures exerted by gun powder and liquid and also piston speed for various construction data, charging conditions and the type of gun powder used*.

The pressure transmitting process of expanding gun powder gases, considering their outflow through an orifice on to a liquid and powder to be compacted, is described by à system of differential-integral equations including :

-equation of piston movement

$$m_1 \frac{d^2X_1}{dt^2} = S_1 P_1 (X_1, X_2, \psi, t) - S_2 P_2 (X_1, X_2) \tag{1}$$

-equation of the sealing case movement

$$m_2 \frac{d^2X_2}{dt^2} = S_2 P_2 (X_1, X_2) - S_2 P_3 (X_2) \tag{2}$$

-equation of gun powder combustion*

$$\frac{d\psi}{dt} = \frac{P_1 (X_1, X_2, \psi, t)}{T_k} \sqrt{H^2 + 4H\lambda\psi} \tag{3}$$

-equation of entrgy balance

$$f \frac{[w \psi - y (F, T)]}{K - 1} - \frac{P_1 (W\psi + S_1X_1)}{K - 1} = \frac{m_1 \left(\frac{dX_1}{dt}\right)^2}{2} - \frac{m_2 \left(\frac{dX_2}{dt}\right)^2}{2} + E_2 + E_3 \tag{4}$$

where

w, m_1, m_2-mass of gun powder, piston and case;

X_1, V_1 and X_2, V_2—displacement and velocity of piston and case;

T_k, H, A, K-characteristic features of gun powder;

We-volume of gun powder chamber during combustion;

ψ, S_1 S_2—cross-section of the piston at the combustion chamber end and working chamber end;

P_1-pressure in the combustion chamber;

P_2, P_3—liquid and powder equations of state;

E_2, Es-work spent in liquid and powder compression;

γ—weight of gas flowing out through the orifice

and

T—pressure impulse.

Computational solution of the differential equation system enabled us to determine the laws of piston movement and velocity, pressure change in gun powder and working chamber and powder briquette porosity with time. The analysis of the data obtained showed wide possibilities to control parameters of the existing hydrodynamic machines from the point of view of obtaining high-quality parts with maximum porosity on account of piston mass reduction, pressure decrease at the initial stage of piston movement and amount of gun powder charge.

Compaction of porous permeable materials has a number of specific properties. On the one hand, it is necessary to obtain maximum porosity. On the other, compaction should provide for obtaining a rather strong structure with uniform properties allowing proper sintering. Improvement of the compact strength is easily obtained by increase in pressure of the working chamber of the hydrodynamic machine, increase in gun powder charge and increase in piston mass.

The results on compaction of tube-type porous elements from titanium powders are presented in the form of dependence of the relative porosity on the amount of charge and piston mass (Fig. 2).

Charge being constant, porosity can change due to mass change of the separating piston. The dependence of relative porosity changes on piston mass for various charges is given in Fig. 3.

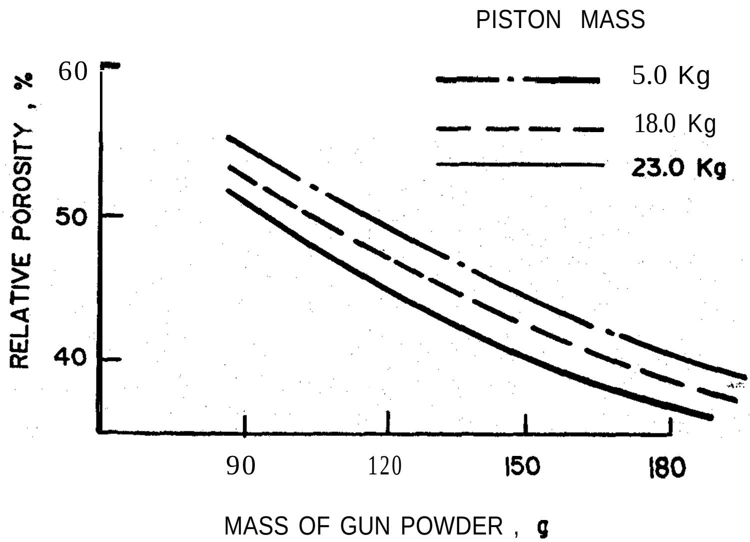

Figure 2. Effect of gun powder charge on porosity for various prston masses.

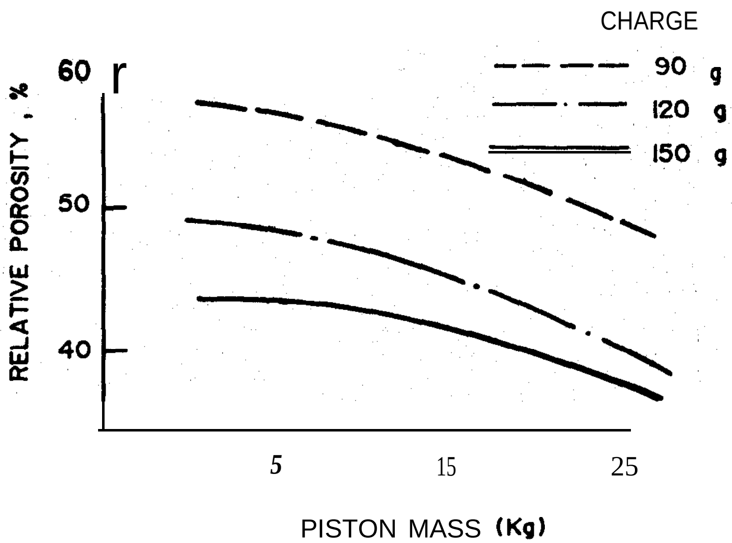

Figure 3. Dependence of relative porosity of briquette on piston mass for various charges.

As it is seen in Figs. 2 and 3, the necessary porosity, which for porous permeable materials is in the range 40-55 per cent, can be obtained either by change in gun powder charge or piston mass.

The hydrostatic compaction' by'dynamic loading within 2-8 m/s increases the structural imperfections in the material that finally enable us to obtain high strength both of compacts and sintered parts. The basis of this phenomenon lies in the higher reduction during the rearrangement stage during hydrodynamic compaction as compared to hydrostatic compaction. This is important in making porous permeable materials for parts with improved properties.

A study of the strength characteristics of nonsintered elements showed that -the strength of hydrodynamic compacts was higher than that of hydrostatic ones by about 12-25 per cent, with the same volume of porosity. ln addition to improvements in mechanial properties, hydrodynamic compaction activates the sintering processes by distorting fine material structure, particle crushing and formation of metal contacts. Sintering is the final-operation during which the properties of porous parts are eventually formed.

The sintering process is substantially influenced by the size of powder particles, their size distribution, surface state, oxide content and crystal imperfections, the lattet depending much on the character of thepreliminary treatment'. During sintering, reduction of pores, their size and shape takes place. The analysis of fractrograms showed that cavities and protrusions on pore surfaces are substantially smoothed out due to surface diffusion processes and atom transfer through .a gas phase.

During sintering at elevated temperatures, there "occurs substantial quantitative growth of metal contacts and pore densification under surface tension. Besides the effect of temperature, shrinkage is effected both by powder particle size and their surface state.

Comparative studies carried out showed that hydrodynamic compaction, as compared to hydrostatic compaction, increases crystal lattice imperfections. This results in the fact that briquettes compacted hydrodynamically shrink during sintering up to 10 per cent and yield the same strengthening characteristics at lower temperatures[5].

Since shrinkage occurs during sintering it is necessary to define the exact size of compacted material so that parts with good dimensional accuracy are obtained. The degree of relative shrinkage for various titanium powders is 8-15 per cent. It is important that shrinkage should be defined in each and every particular case.

Sintering temperature exerts great influence on the change of pore structure. The' quantitative data pertaining to pores are presented in Table 1. The given data shows that both pore size and permeability increase with initial powder particle size. But pore size increases and permeability decreases with increase in sintering temperature. The data enables us to choose a proper sintering temperature depending on the required filter characteristics. Holding time during sintering was determined depending on the mechanical strength required of sintered elements. Temperature of IOOO-1050°C and holding times of 180-240 min. are optimum conditions for sintering of titanium porous elements.

Table 1. Dependence of filtering character&s on particle size and sintering temperature

Powder particle size (μm)	Sintering temperature (°C)	Density (g/cm³)	Porosity	Permeability co-efficient (×10⁹ cm?)	Pore size (μm) max	Pore size (μm) min
+0.5—0.4	900	2.48	0.45	108	76	69
	950	2.58	0.42	141	72	64
	1050	2.71	0.40	96	70	62
	1150	2.75	0.39	94	69	60
+0.4—0.315	900	2.39	0.47	80	65	57
	950	2.48	0.45	83	63	55
	1050	2.58	0.42	81	60	52
	1150	2.71	0.40	78	58	44
+0.2—0.16	900	2.48	0.45	38	52	35
	950	2.61	0.43	36	40	32
	1050	2.66	0.41	32	37	29
	1150	2.71	0.40	30	35	26
+1.0—0.63	900	2.16	0.52	181	197	169
	950	2.39	0.47	177	192	164
	1050	2.48	0.45	172	189	160
	1150	2.12	0.43	170	183	159
+1.0—0.515	900	2.25	0.50	164	180	135
	950	2.34	0.48	160	170	127
	1050	2.48	0.45	166	162	122
	1150	2.52	0.44	164	158	119

The main parameters characterising both structure and porous body are the permeability coefficient, the average and maximum pore sizes. Besides their quantitative values, particularly for the elements with H/D $>$ 5, uniformity in distribution is the most important factor in practice. The result of distribution uniformity studies is presented in Table 2. It shows a rather uniform porosity and permeability distribution along the specimen length. It speaks in favour of hydrodynamic compacting method to obtain porous elements with large length.

Hydrodynamic compacting method enables us to obtain large parts of complex shapes from various materials having uniform density. Filtering elements made of titanium powder are shown in Fig. 4.

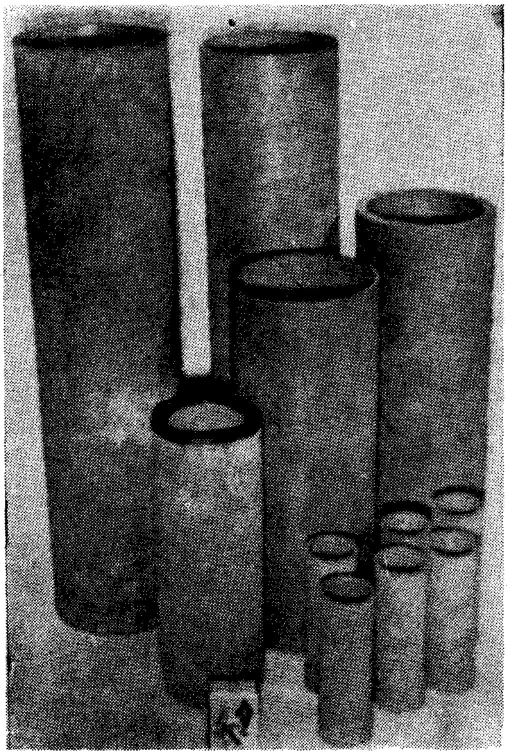

Figure 4. Filtering elements from titanium powder produced by hydrodynamic compaction.

Table 2. Hydraulic characteristics of porous titanium elements

Particle size (μm)	Porosity	Permeability coefficient ($\times 10^9$ cm^2)	Pore size (μm) max	Pore size (μm) min
(1)	(2)	(3)	(4)	(5)
+0.18−0.315	0.53	42	53	35
	0.51	41	51	34
	0.48	42	50	34
	0.52	44	55	37
	0.51	42	52	35
	0.51	42	51	34
	0.55	44	58	39
	0.52	43	53	36
	0.51	41	52	34
	0.54	43	56	37
Average value	0.52	42.4	55.1	35.5
Average statistic deviation	±0.013	±1.3	±1.8	±1.4

(*contd.*)

Table 2 (contd.)

(1)	(2)	(3)	(4)	(5)
+0.315−1.0	0.47	117	161	123
	0.45	117	161	124
	0.44	120	168	127
	0.46	117	162	122
	0.44	116	162	122
	0.46	119	163	124
	0.48	112	162	123
	0.43	116	160	122
	0.44	116	156	118
	0.45	115	162	122
Average value	0.45	116.5	162.7	122.7
Average statistic deviation	+0.012	±1.6	t2.2	±1.6

References

1. Karpick, E., ***Steel*, *131*** (1952).
2. ***Iron Age*, *170* (1952).**
3. **McKennon,** U.S. Patent, 2.648.125 (1963).
4. Roman, 0. V., Anashchenko, M. P., Boiko, YU. V., Shelegov, V. I., 'Pressovanniye poroshkovikh materialov energiey porokhov'. V kn. : Gidrostaticheskaya obrabotka metallov. Tezisi dokldov II VsesoYuznoy konferentsii. Donetsk, 1981, p. 168-169.
5. Serebryakov, M. V., Bnytrennyaa balistika stvolnikh system i porokhovikh raket.-M. : Oborongiz, 1962, p. 704.
6. Roman, 0. V., Impulsnoye formovaniye poroshkovikh materialov vzrivom. Novosibirsk, 1982, p. 157-162 & 315.
7. Afanasiyev, L. N., Roman, 0. V., Issledovaniye tonkoy stryktyri zheleznikh briketov, spressovannikh gidrodinamicheskim metodom., p. 119-120.
8. **Belov,** S. V., Poristrie materiali v mashinostroenii.—M. : Mashinostroenie, 1976, p. 184.