

Investigation of Magnetic Pulse Deformation of Powder Parts

V. Mironov¹, M. Kolbe², V. Zemchenkov³, A. Shishkin⁴

^{1,3,4} Riga Technical University, BF, LV-1048, Riga, Latvia, Viktors.Mironovs@gmail.com

² Westsächsische Hochschule Zwickau, Institut für Produktionstechnik, Zwickau, Germany. Matthias.Kolbe@fh-zwickau.de

Abstract

Current article covers basics of powder compaction by electromagnetic impulse field and research results of sintered Fe powder part deformation process. This work is a joint research carried out by Riga Technical University (Latvia) and the Westsächsische Hochschule Zwickau (Germany).

Keywords

Deformation of powder parts, powder compression

1. Introduction

Assembling operations performed by electromagnetic pulsed treatment (**TEMIF - treatment by electromagnetic impulsed field**) are the most common technological processes where pulsed electromagnetic fields are used. TEMIF application allows to produce one-piece compounds (mostly cylindrical shape) with variable density, as well as to obtain joints that resist to axial and torsional loads [1].

Assembling is performed by simultaneous deformation of joined parts, or by plastic deformation of one workpiece in flutes or cutouts of other workpiece [2].

For the first time crimping process of steel powder parts to the mandrel for obtaining a permanent joint was described in [3]. This method has proved effectiveness for worm wheel blanks manufacturing, tools processing, and tools for thermoplastics moulding [4].

In [5], [6] application of the TEMIF method for obtaining compounds made of powder parts on the basis of Fe-C (WC-Co) alloys is described. Meanwhile, the following paper [7] focuses on forming processes of pre-sintered preforms made of Fe-C-Cu materials. Analysis and modelling of the TEMIF processes are presented in [8]. In the same time, practical applications of TEMIF for manufacturing of parts made of various powder materials were presented in [9],[10], [11].

2. Basics of Powder Compaction

"Pulse compaction" is defined as a process for compacting powder under the influence of pulsed loads. These procedures are divided into explosive compacting, magnetic force compacting and electro-hydraulic compacting. For unsintered work pieces were achieved theoretical densities of 75% to 95% and 1.5 - 1.8 times more compressive strength. [10]. The following describes the magnetic force of compaction using the effect of the electromagnetic pressure on the powder to be compacted. The direct magnetic force compaction - a driver of electrically conductive material is used. Does the electromagnetic pressure work on tool parts, which are accelerated due to the energy input and hitting the powder, the indirect magnetic force compaction is used. The magnetic force compaction is a very complex process with many influencing factors on the compaction results (Figure 1).

<u>Compaction Results</u>		
<u>Workpiece dimensions</u>	<u>Properties of the powder</u>	<u>Electrical parameters</u>
<i>powder mass</i>	<i>material</i>	<i>electromagnetic pressure</i>
<i>wall thickness</i>	<i>particles form</i>	<i>frequency</i>
<i>workpiece form</i>	<i>particle size</i>	<i>discharge energy (capacity,</i>
<i>voltage)</i>	<i>pretreatments</i>	<i>coil properties</i>
	<i>additives</i>	<i>driver properties</i>
		<i>gap between coil and driver</i>

Figure 1: Overview of factors influencing the compaction results

Great interest has the direct radial compression of rod-shaped or tubular parts with a length to diameter ratio greater than 2.5.

The production of rod-shaped parts encounters the following difficulties:

- Transverse cracking by axially acting tensile stresses during the compression process
- Density drop in the radial direction, inhomogeneity of the density and strength

Tubular parts can be manufactured with wall thicknesses up to 8 mm with good density distribution in the radial direction by magnetic force compaction using a driver. Depending on the powder material and theoretical discharge energy densities between 60% and 95% are achieved (Figure 2 [11]).

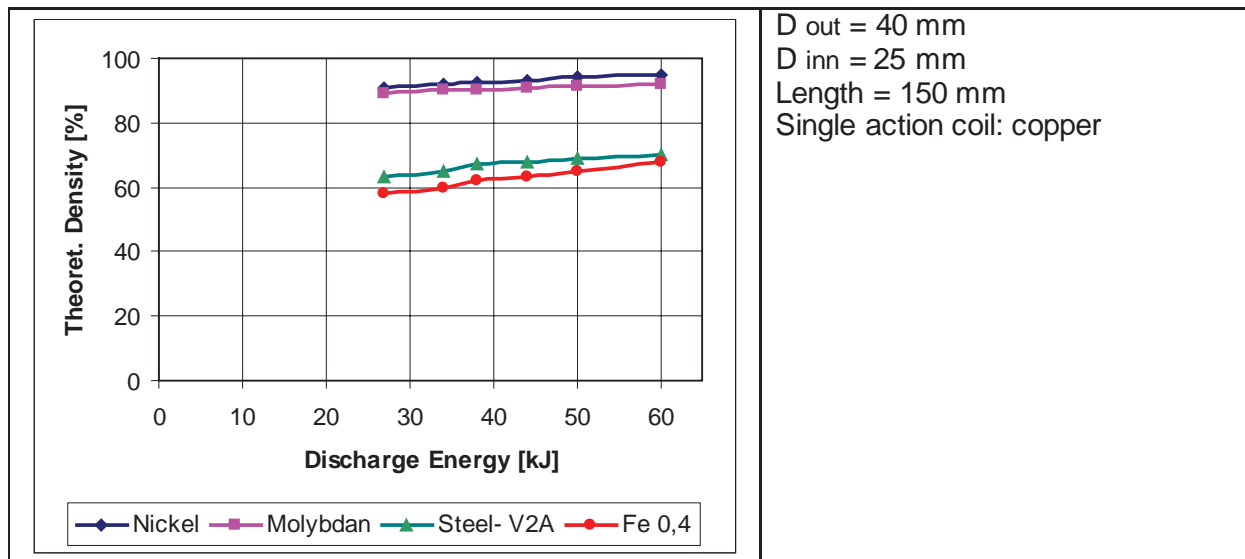


Figure 2: Theoretical densities electromagnetically compacted powder samples of different materials [11]

3. Theoretical Background of TEMIF

A particular characteristic of sintered powder materials is its residual porosity (which may vary 3-20%), which on the one part leads to increasing the flexibility of the final product and on the other part may reduce its strength. Application of TEMIF process acts as an ancillary compaction which leads to irregularity of the density of powder workpiece.

The presence of residual porosity reduces an electrical conductivity and magnetic permeability of the sintered billet, which leads to decreasing of electromagnetic pressure to the workpiece. In this case the electromagnetic pressure can be determined by the following expression:

$$p(t) = \frac{H_m^2 \mu \mu_0}{2} e^{-\beta t} \sin^2 \omega t, \quad (1)$$

where:

H_m - magnetic field strength in the gap of the coil-workpiece,

μ - magnetic permeability of the workpiece material,

μ_0 - permeability of vacuum,

β - damping of discharge current,

ω - current's angular frequency.

Knowing the stored energy, the magnetic field can be defined as:

$$H_m = \frac{I_{max} n}{l}, \quad (2)$$

where:

I_{max} - peak value of discharge current,

n - number of turns in the winding (coil),

l - length of winding.

The magnitude of electromagnetic pressure on the powder workpiece can be determined as:

$$p(t) = \frac{I_{max}^2 n^2 \mu \mu_0}{4l^2} e^{-\beta t} \sin \omega t k_1 k_2, \quad (3)$$

where:

k_1 - factor, which takes into account a magnetic field pressure decrement (due to porosity) to the powder body,

k_2 - factor, which takes into consideration the effect of the gap between coil and workpiece.

Pressure required for plastic deformation of powder workpiece p_d , can be expressed as:

$$p_d = 2\sigma_s \ln \left(\frac{c_0}{c} \right), \quad (4)$$

where:

σ_s – tensile strength of powder workpiece,

C_0, C - initial and final density of powder workpiece.

4. Experimental Studies of TEMIF

Experimental studies were carried out on the equipment BBC-60 of the WHZ Zwickau (Figure 3). Main parameters of BBC-60 are given in Table 1.

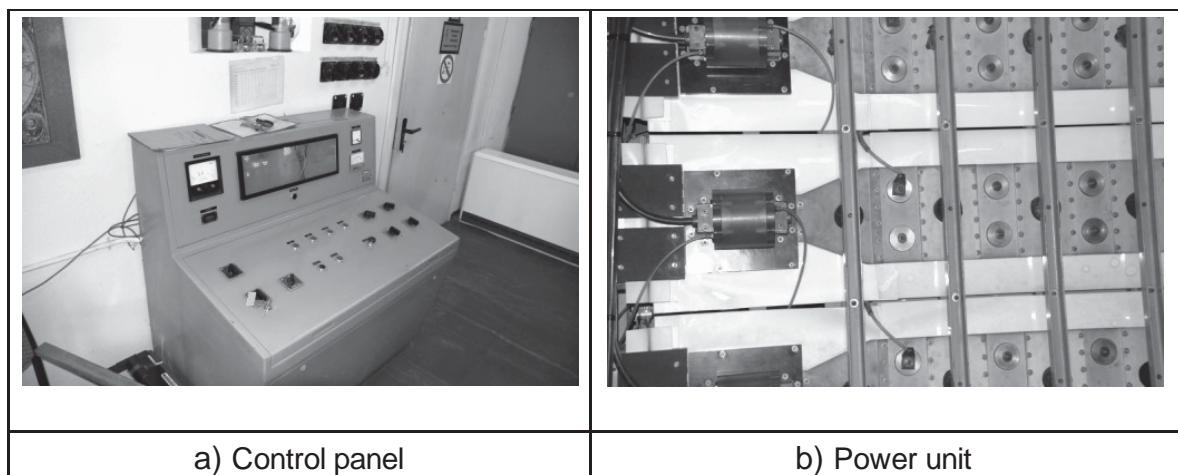


Figure 3: Components of the BBC-60 (Westsächsische Hochschule Zwickau)

Storage capacity, μF	7,71-308,4 (stepped)
Operating voltage, kV	10-20 (through 1 kV)
Charging time, s	20
Charging current, mA	320 (max)
Stored energy, kJ	1,5-60
Discharge current (in short-circuited mode) (max), kA	1250 (at 308.4 μF , 20 kV)
Discharge current (min), kA	60 (at 7.71 μF , 10 kV)
The frequency of discharge (min.), kHz	37 (at 308.4 μF)
Discharge frequency (max.), kHz	125 (at 7.71 μF)
Power (of power supply), kW	10

Table 1. Main parameters of BBC-60 Solenoid-type single-action coils made of insulated copper wire are shown on Figure 4a).

There is no mechanical banding for such coils, so they were destroyed during the passage of the impulsed current. Since the coils have a certain weight, the inertia processes takes some time before its destruction. Such a very short time period is sufficient for acceleration of workpiece deformation.

Single-action coils are cheap and easy for wiring. Yet their effectiveness in some cases is higher than for reusable coils. Single-action coils are very convenient for experiments to set the parameters for subsequent series production. For safety reasons coils were placed in a special reusable protective case, and experiments were conducted inside of protective chamber (Figure 4b).

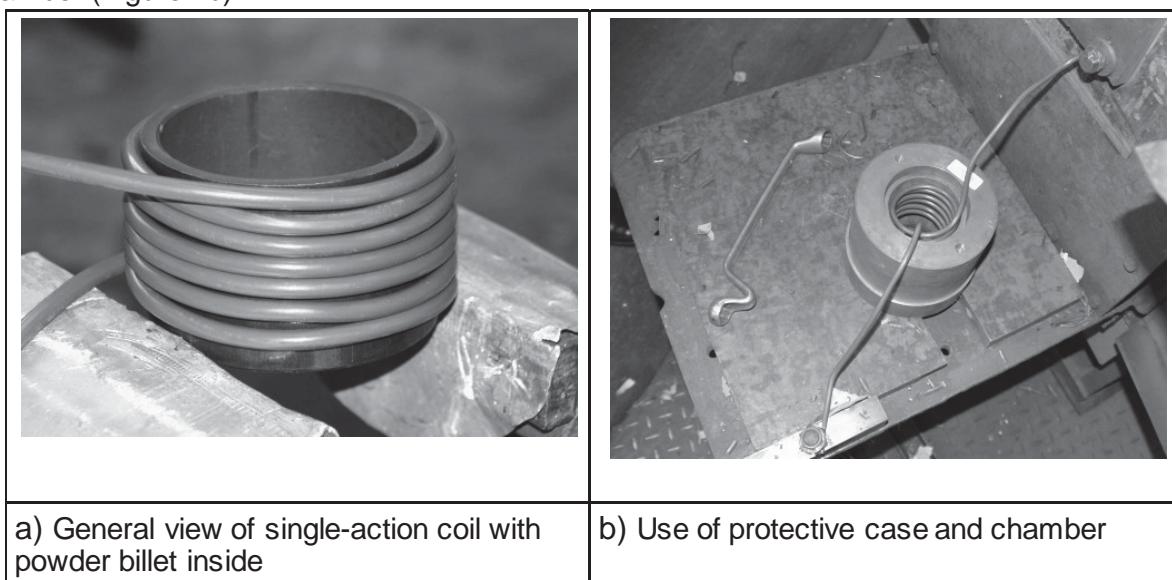


Figure 4: Single-action coils for TEMIF of powder workpiece

Coil parameters are listed in Table 2.

Wire diameter (with insulation), mm	5,5
Diameter of Conductor (Copper), mm	3.5
Number of turns	5
Inductance, μH	0.04

Table 2: Parameters of the single-action coils

For TEMIF experiments we have chosen a ferrous powder PM-28N (produced by Höganäs AB (Sweden)), which is used for manufacturing of sintered bearings. Main parameters of powder parts for TEMIF process are listed in Table. 3.

Density, g/cm^3	6.0-6.6
Porosity, %	18-23.
Hardness, HB	90-120
Chemical composition, %	C = 0,6; Ni = 2,5-4,0; Cu = 1,5; Mo = 0,5; Fe – rest.
Dimensions (External diam. X Internal diam. X Height), mm	40x30x13 and 80x70x19 (55)

Table 3: The parameters of powder parts for TEMIF process

Powder parts used in experiments have been exposed to sintering at 1150 °C in endogas atmosphere.

Two TEMIF options were used: (a) - powder parts free radial deformation, and (b) - press-fitting on a steel mandrel; Hardness of the mandrel after heat-hardening - HRC 56-58, surface roughness 0.1 (Figure 5a). A special set of experiments was carried out with mandrel made of sintered powder (Figure 5b).

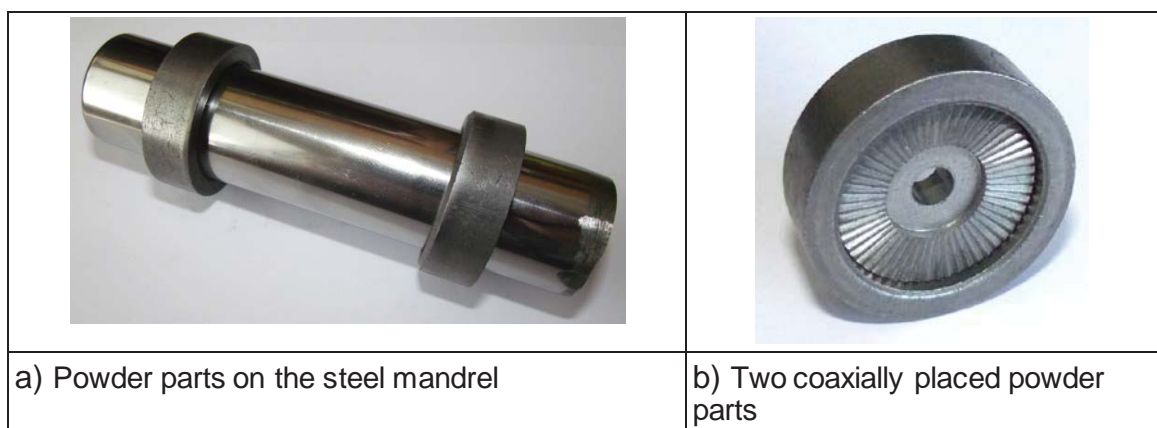


Figure 5: Powder parts before TEMIF process

The experiments were carried out by varying different parameters of BBC-60: operating voltage from 10 to 15 kV, discharge frequency from 37 to 125 kHz, and the discharge energy level from 10 to 18 kJ.

It was found that the frequency of the discharge contributes to an increase in the amplitude of electromagnetic pressure and rate of deformation, which leads to increase the final density of the product up to 5%. However, the increase in discharge frequency over 100kHz leads to powder part cracking, or in some cases, to the lack of binding between powder part and the mandrel (Figure 6a). One of possible reasons for lack of binding is a rebound force from the mandrel (due to the effect of magnetic pad [7]). Increased magnetic pressure may also lead to detachment of individual powder part fragments (Figure 6b).

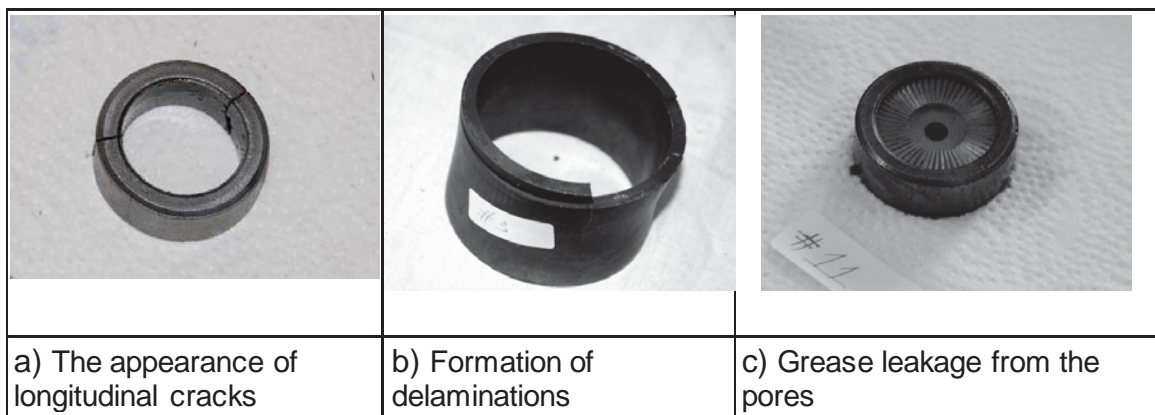


Figure 6: Defects of powder blanks after TEMIF processing

During a TEMIF process a passage of pulse currents through the workpiece provoke a temperature increase up to 100-150 °C. To confirm this fact, an experiment was conducted using powder parts pre-impregnated with oil. After the process of crimping, leakage of hot oil from the pores of powder workpiece was observed (Figure 6c).

It was found that radial clearance between inner surface of the deformable part and the mandrel has big influence on the forming of joint between powder parts. It was also found that binding quality increases for mandrels made of unhardened steel.

The adhesion strength between mandrel and powder parts as well as between two powder parts has been investigated. The pressure invoked by TEMIF process has been calculated by using the equations (1, 3). Adhesion strength has been evaluated by axial displacement method; obtained results are shown in (Figure 7).

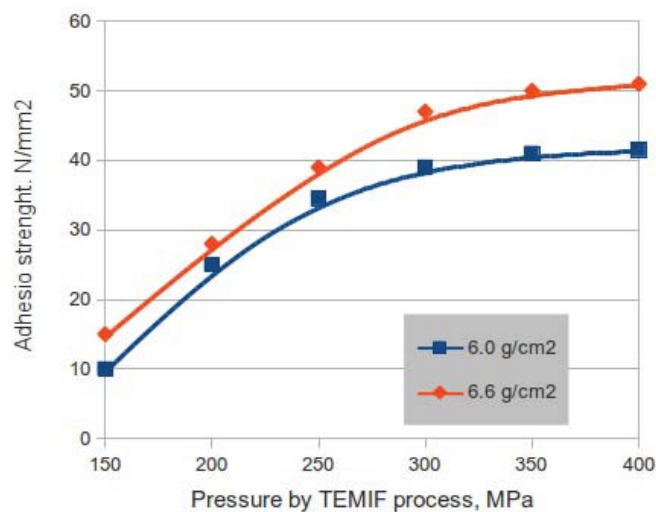


Figure 7: Relationship between adhesion strength and electromagnetic pressure for powder parts of different density

5. CONCLUSIONS

- TEMIF process may be effective for deformation and joining of workpieces made of powder steels.
- The degree of deformation depends on properties of workpiece and mandrel materials.
- In some cases, a significant pressure increase may lead to destruction of powder part.
- Further investigations are planned using the new electromagnetic power unit - Poynting SMU SSG 3020 - at the University of Zwickau [12].

6. REFERENCES

- [1] F. Wilson: *High Velocity Forming of Metals*, 1964
- [2] V. Shribma: Take advantage of the new magnetic pulse welding process. *Svetsaren, a Welding Review*, 2001, p.14-16
- [3] V. Mironov: Pulververdichten mit Magnetimpulsen, Plansee-Bericht fuer Pulvermet., Vol. 24, 1976, pp.175-190.
- [4] N. Dorozhkin, V. Mironov, V. Vereshchagin, and A. Cat: Electro methods for coating of metal powders, Riga, Riga Zinatne, 1985
- [5] V. Mironov and H. Wolf: Verdichten von Metallpulvern durch elektromagnetische Kräfte, *5.III Wiss. Konf. der IHZ*, Zwickau: 1979, pp.128-129
- [6] V. Mironov and H. Wolf, Pulververdichten durch elektromagnetische Kräfte Herstellungsmöglichkeit für Werkzeugaktivelements, *Fertigungstechnik*, 1980, pp.558-590

- [7] *V. Mironov, V. Zemchenkov, and V. Lapkovsky: Model of the Magnetic packings of dispersed materials," Transactions of the VŠB-Technical University of Ostrava, 2009, pp.249-253*
- [8] *A. Mamalis, D. Manolakos, A. Kladas, and A. Koumoutsos: Electromagnetic forming and powder processing: Trends and developments, Applied Mechanics Reviews, vol. 57, 2004, p.299*
- [9] *B. Chelluri and E. Knoth: Powder Forming Using Dynamic Magnetic Compaction, 4th International Conference on High Speed Forming, 2010, pp.26-34*
- [10] *H. Wolf: Application of Electromagnetic Forces for Powder Compaction and Joints, Proc. of the 7th International Conference of High Energy Rate Fabrication, Leeds, UK: 1981*
- [11] *M. Meinel: Magnetkraftverdichten, Verfahren des Impulsverdichtens – einige technologische Aspekte, Kolloquium Elektromagnetische Umformung, Uni Dortmund, WHZ Zwickau, 2001*
- [12] *Ch. Beerwald: Anlage zur elektromagnetischen Umformung –SMU SSG 3020, Poynting GmbH Dortmund, 2010, www.poynting.de*

