بسم الله الرحمن الرحیم

Course Title: **Advanced Powder Metallurgy**

Weekly Hours: 2.0 semester hours per week (2 SWS)

Course schedule: Wednesdays, 13:00–15:00, Room 2.15

Lecturer: Prof. Dr. Maziyar AZADBEH

2nd semester of the academic year 1404-1403

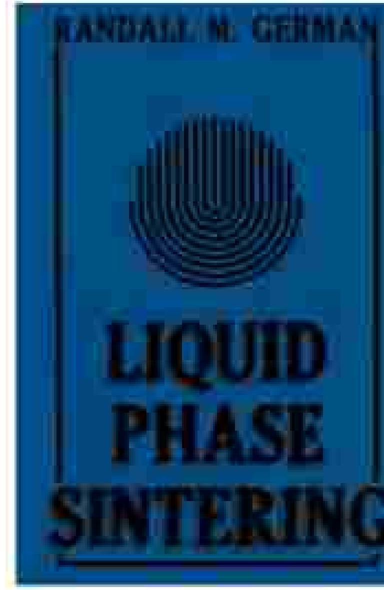
References

1) Metals Hand book ,Powder Metallurgy, Vol.7, 9th edition, ASM,Metals Park OH, 1984.

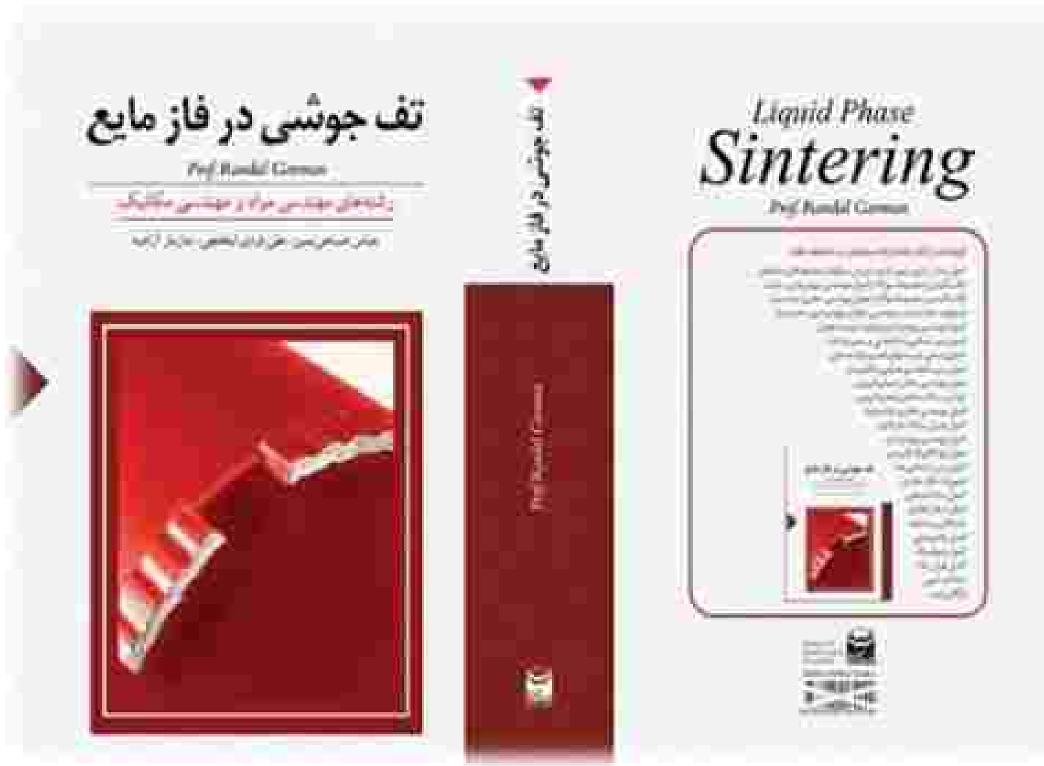
2) R.M.German, "Powder Metallurgy Science" 2nd Edition,Metal Powder Industries Federation,Princeton,NJ,1994.

3) R.M.German, "Powder Metallurgy of Iron and Steel",A Wiley Interscience Publication,1998.

4) R.M.German, "liquid Phase Sintering", Plenum Press – New York and London,1985.



معرفی کتاب
سرشناسه
:
جرمن، رندال ام.، ۱۹۴۶ - م.
German, Randall M
عنوان و نام پدیدآور
:
تف جوشی در فاز مایع: گلچین رشته‌های وابسته به علوم مهندسی مواد و مهندسی مکانیک/ رندال م. ژرمن؛ مترجمان عباس صباحی‌بین، علی فرجی‌الخجی، مازیار آزاده
مشخصات نشر
:
تهران: ستایش، ۱۳۹۱
مشخصات ظاهری
:
۳۰۰ص: مصور، جدول.
شابک
:
۱۶۰۰۰۰ ریال 978-600-5184-58-7
تیراژ
:
۱۰۰۰ جلد
شماره کتابشناسی ملی
:
۲۹۶۵۰۲۹



J Mater Sci (2009) 44:1–39
DOI 10.1007/s10853-008-3008-0

REVIEW

Review: liquid phase sintering

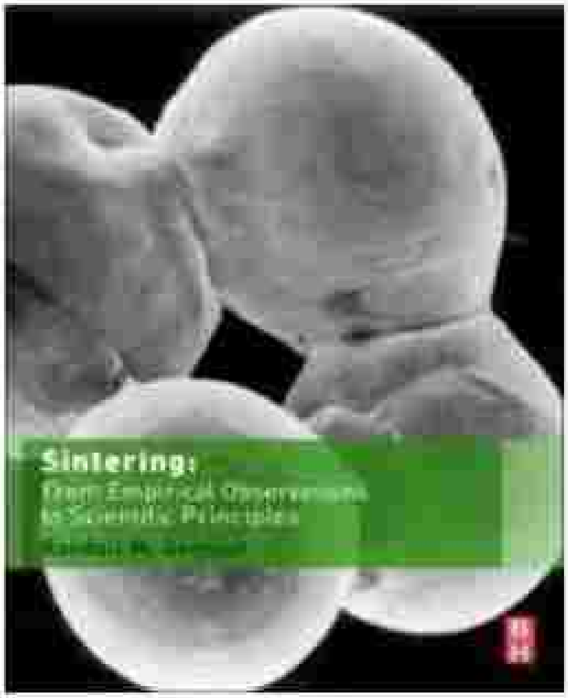
Randall M. German · Pavan Suri · Seong Jin Park

Received: 22 May 2008 / Accepted: 16 September 2008 / Published online: 11 December 2008

Abstract Liquid phase sintering (LPS) is a process for forming high performance, multiple-phase components from powders. It involves sintering under conditions where solid grains coexist with a wetting liquid. Many variants of LPS are applied to a wide range of engineering materials. Example applications for this technology are found in automobile engine connecting rods and high-speed metal

C	Solid concentration in the matrix, m^3/m^3 or dimensionless
C_G	Grain connectivity, dimensionless
C_{SS}	Contiguity, dimensionless
D	Particle size, m (convenient units: μm)
D_1	First eigenvalue of diameter of curvature, m (convenient units: μm)

5) RANDALL M. GERMAN, "SINTERING FROM EMPIRICAL OBSERVATIONS TO SCIENTIFIC PRINCIPLES", Elsevier, 2014



SINTERING
FROM EMPIRICAL OBSERVATIONS TO SCIENTIFIC PRINCIPLES

RANDALL M. GERMAN

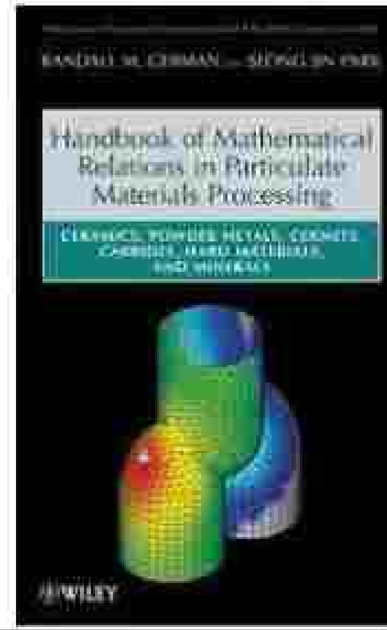
Butterworth-Heinemann is an imprint of Elsevier
225 Wyman Street, Waltham, MA 02451, USA
The Boulevard, Langford Lane, Kidlington, Oxford, OX5 1GB, UK

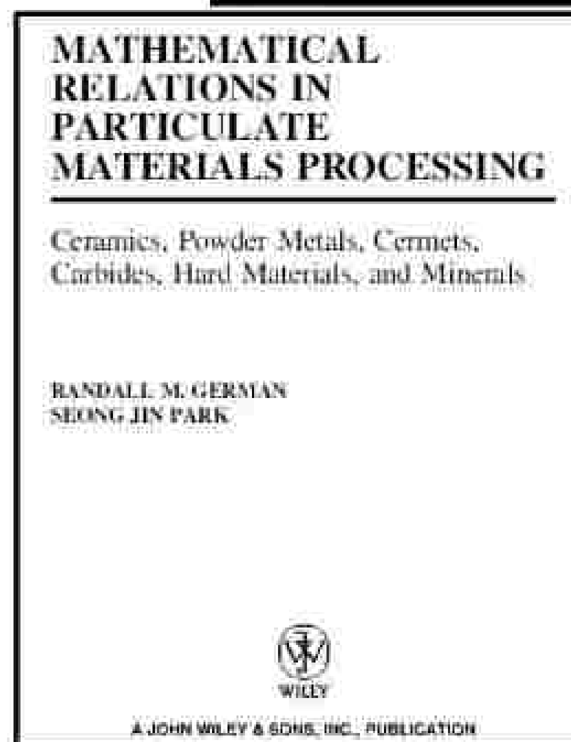
First edition 2014

ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO
Butterworth-Heinemann is an imprint of Elsevier

6) RANDALL M. GERMAN, “MATHEMATICAL RELATIONS IN PARTICULATE MATERIALS PROCESSING”, Published by John Wiley & Sons, Inc., 2008



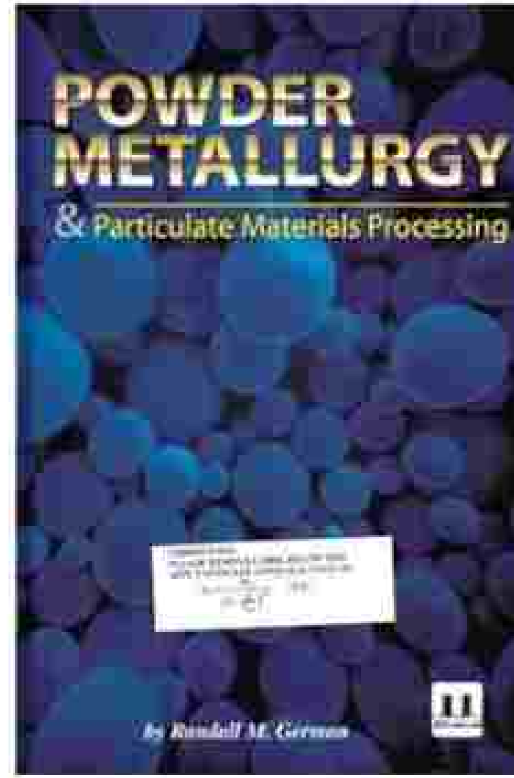

MATHEMATICAL RELATIONS IN PARTICULATE MATERIALS PROCESSING

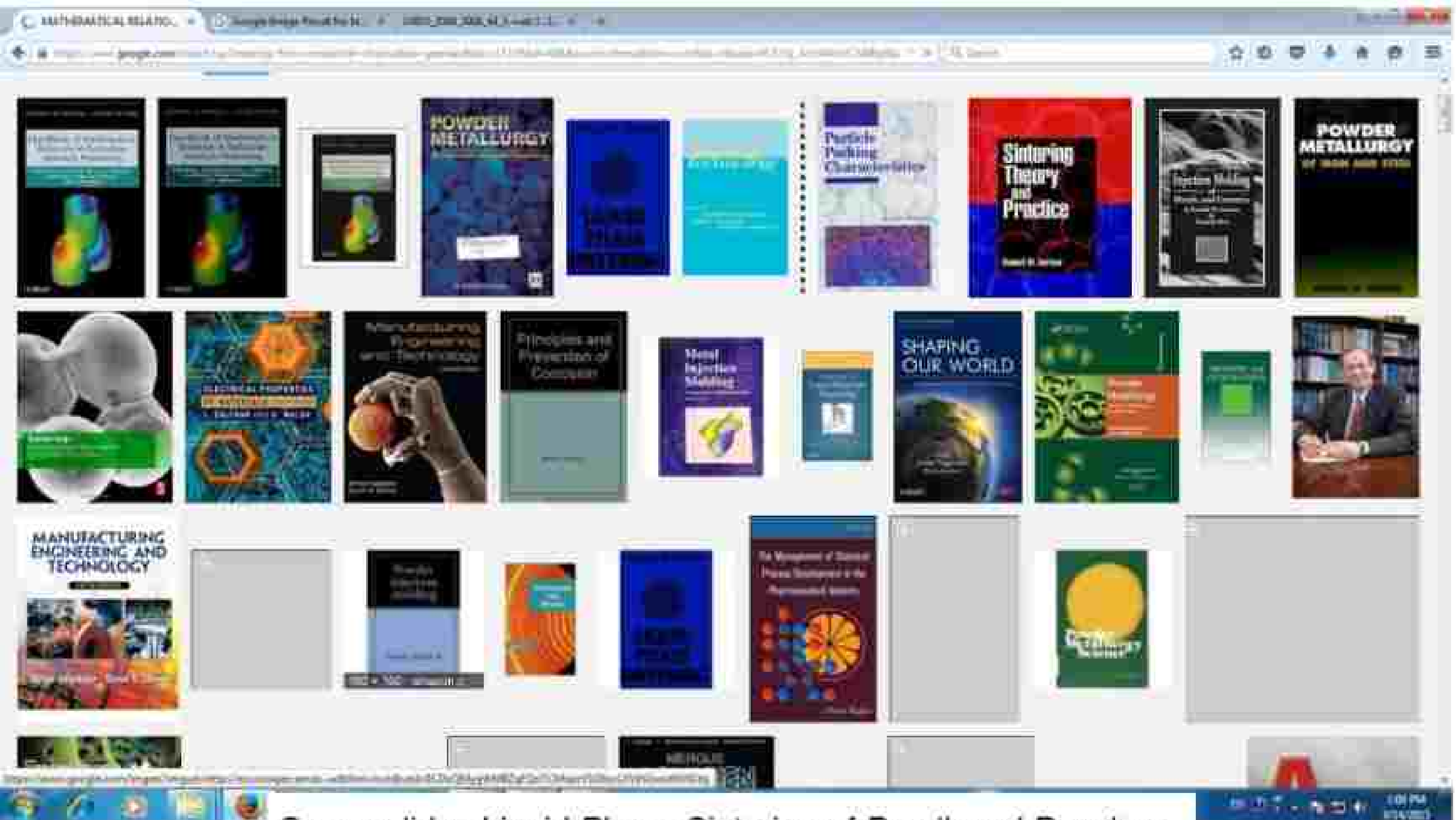
Ceramics, Powder Metals, Cermets, Carbides, Hard Materials, and Minerals

RANDALL M. GERMAN
SEONG JIN PARK

WILEY

A JOHN WILEY & SONS, INC., PUBLICATION


POWDER
METALLURGY
& Particulate Materials Processing
by Randall M. German

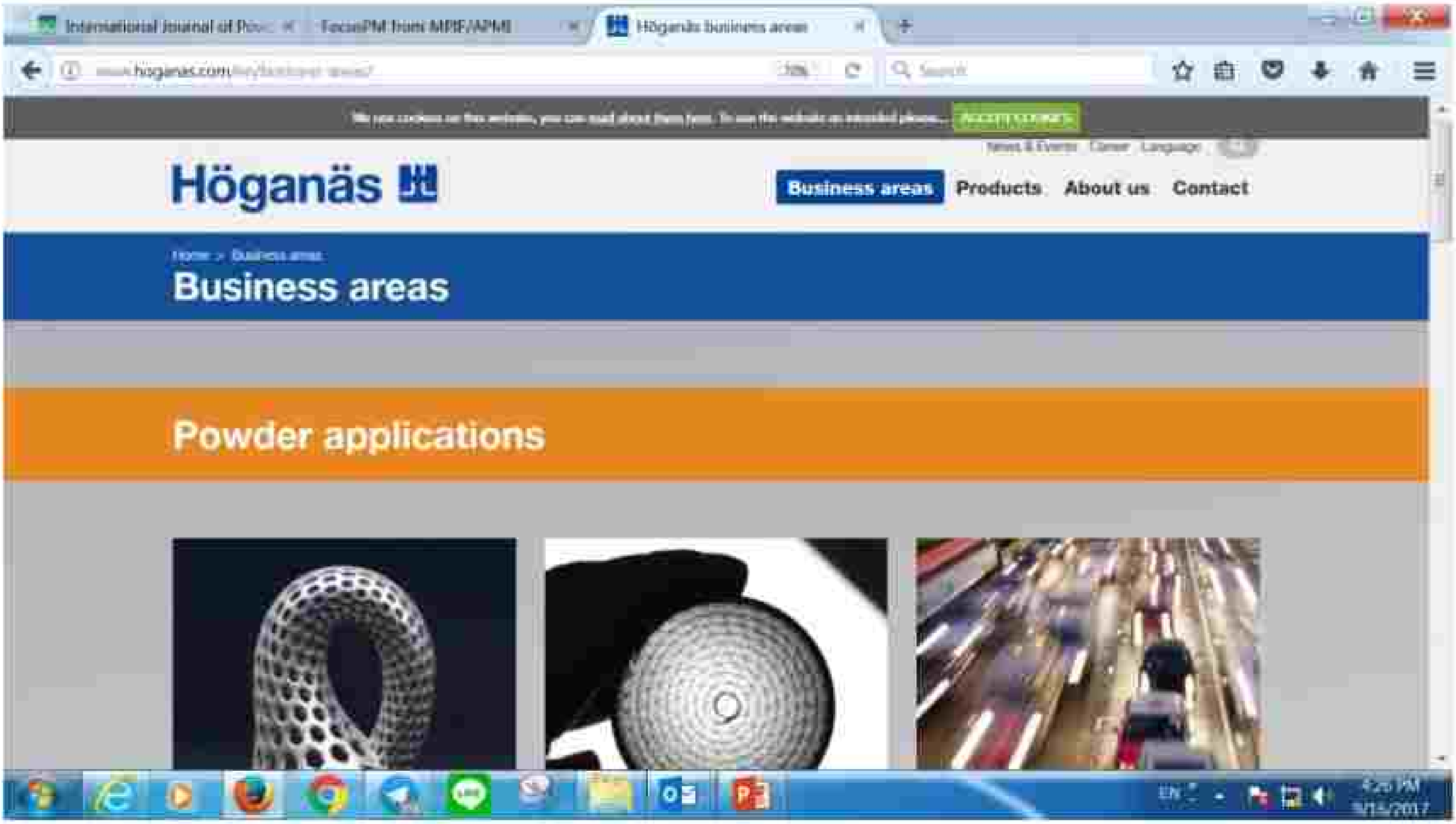


Supersolidus Liquid-Phase Sintering of Prealloyed Powders

RANDALL M. GERMAN

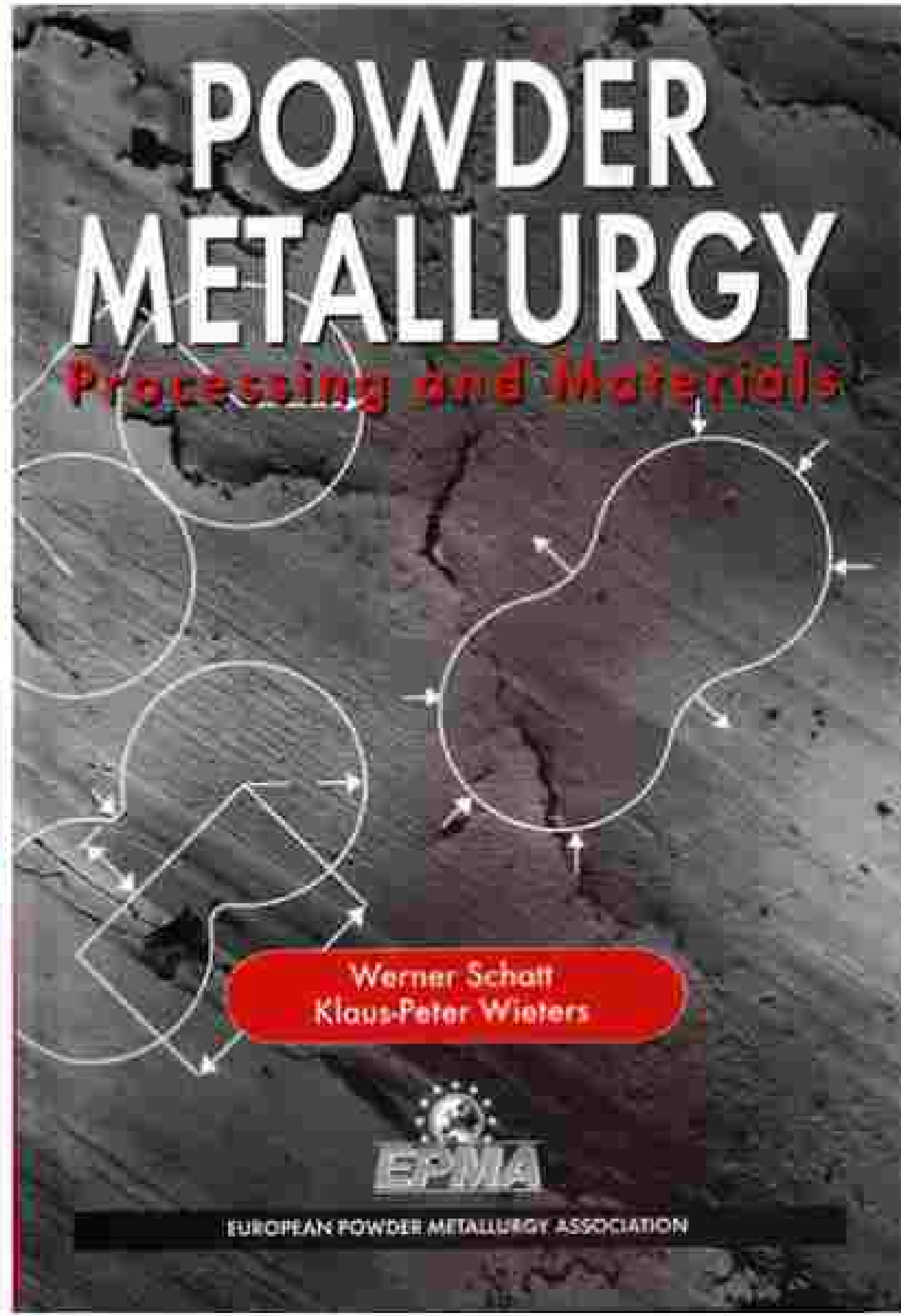
A model is derived for the sintering densification of prealloyed particles that form internal liquids when heated over the solidus temperature. The model considers the powder size, composition, and microstructure, as well as the processing conditions of green density, heating rate, maximum temperature, hold time, and atmosphere. Internal liquid forms and spreads to create an interparticle capillary bond that induces densification during sintering. Densification is delayed until the particles achieve a mushy state due to grain boundary wetting by the internal liquid. This loss of rigidity and concomitant densification of the semisolid particles depends on the grain size and liquid quantity. Viscous flow is the assumed densification mechanism, where both viscosity and yield strength vary with the liquid content and particle microstructure. Densification predictions are compared to exper-

7) Höganäs Handbook for sintered components

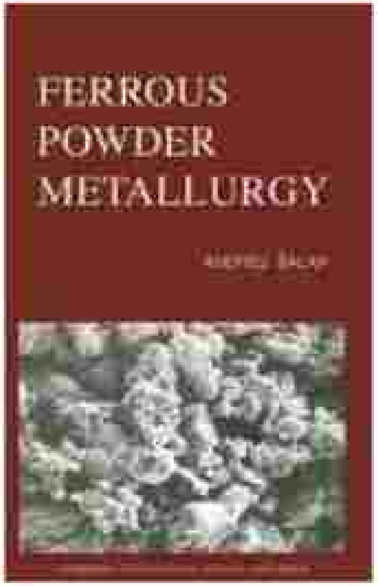


http://www.hoganas.com/en/business-areas/

8) W.Schatt and K.P.Wieters,
“Powder Metallurgy,Processing and Materials”,
European Powder Metallurgy Association(EPMA),
Shrewsbury,
1997.

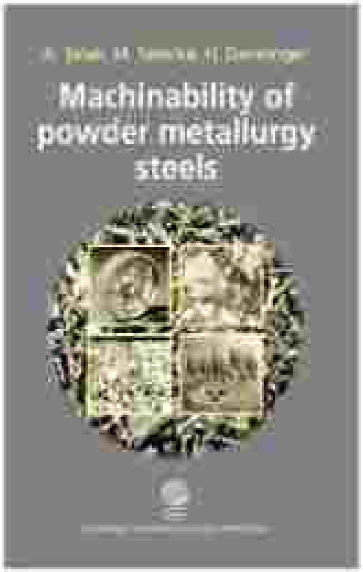


9) Salak, Andrej.; Riecansky, V., Ferrous Powder Metallurgy, Cambridge International Science Publishing, 1995

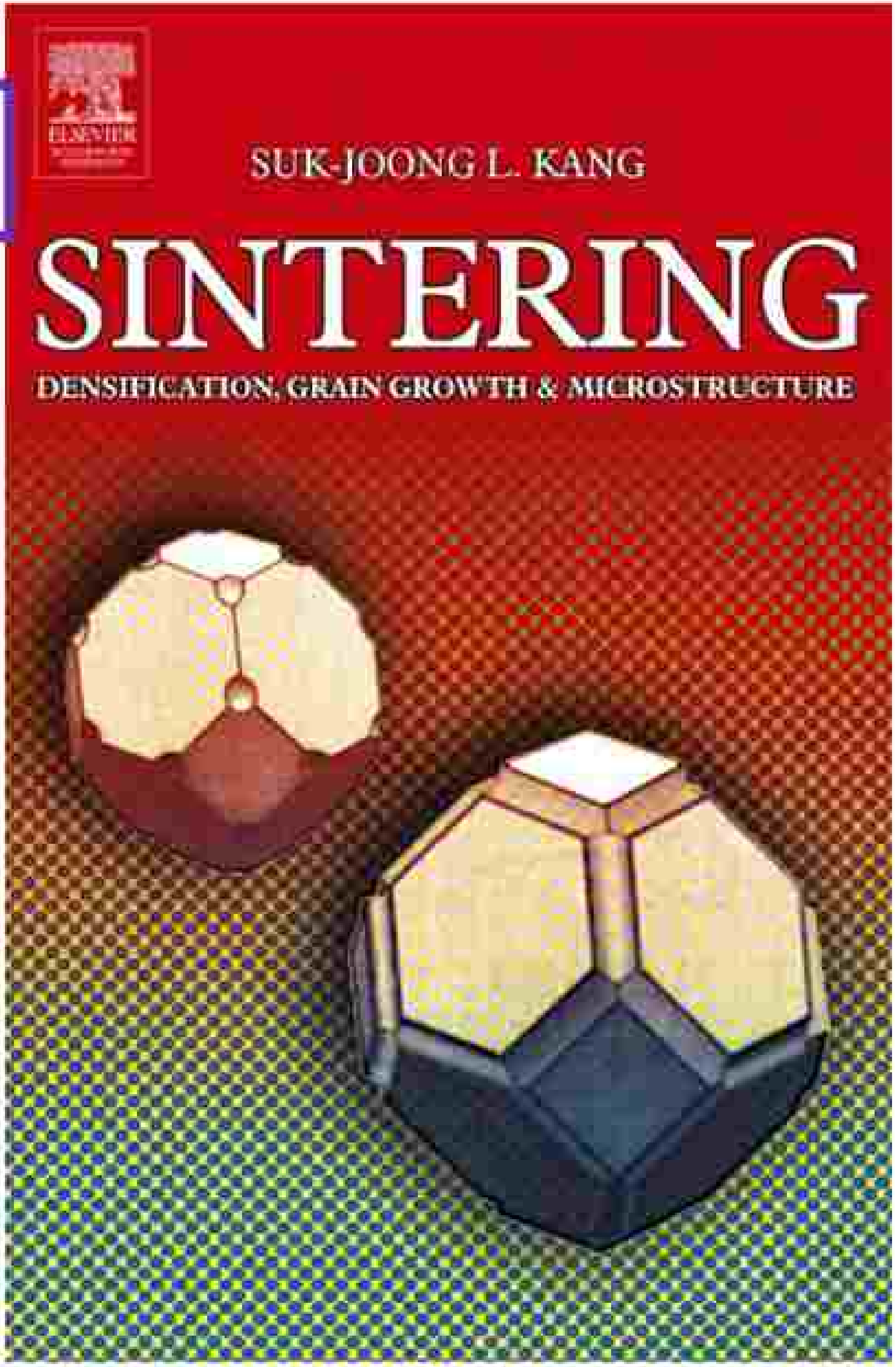


title: Ferrous Powder Metallurgy
author: Salak, Andrej.; Riecansky, V.
publisher: Cambridge International Science Publishing
isbn10 | asin: 1898326037
print isbn13: 9781898326038
ebook isbn13: 9780585165790
language: English
subject Powder metallurgy, Iron--metallurgy, Steel--metallurgy.
publication date: 1995
lcc: TN705.S25 1995eb
ddc: 671.37
subject: Powder metallurgy, Iron--metallurgy, Steel--metallurgy.

10) A.Salak,M.Selecka,H.Danninger, “Machinability of Powder Metalllurgy Steels”,
Cambridge International Science Publishing, 2005.



11) Suk-Joong L.Kang, “Sintering”, Elsevier, 2005



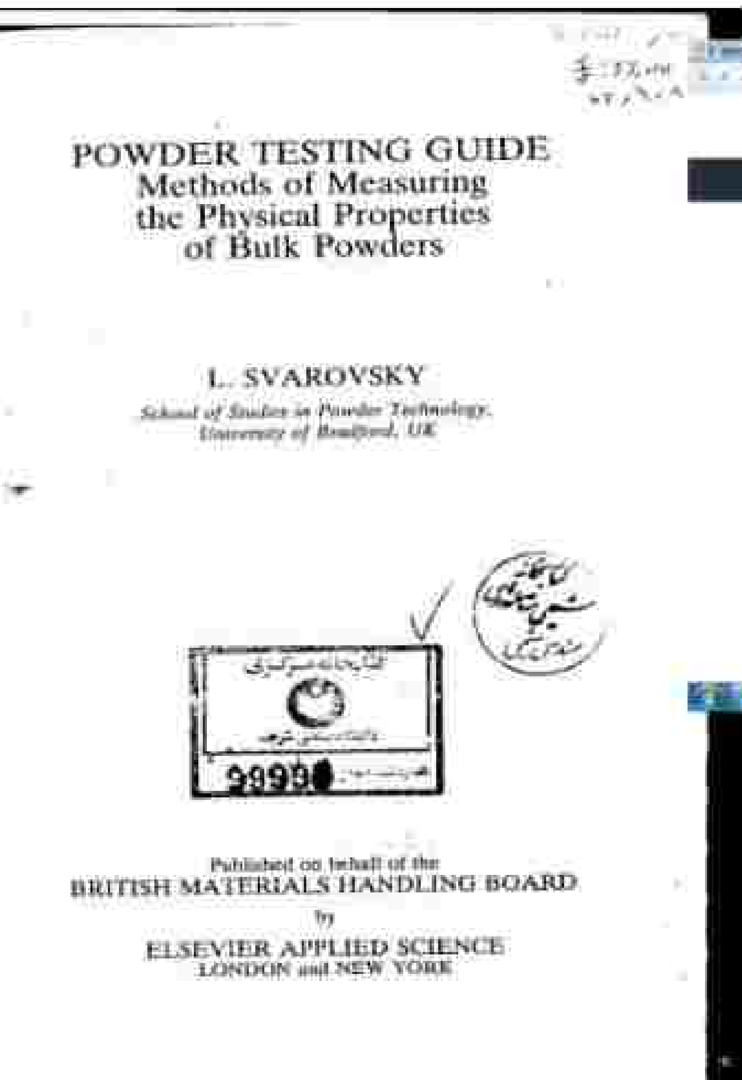
POWDER METALLURGY TECHNOLOGY

G S UPADHYAYA

CAMBRIDGE INTERNATIONAL SCIENCE PUBLISHING

Powder Testing Guide

Methods of measuring the physical properties of bulk powders


POWDER TESTING GUIDE
Methods of Measuring
the Physical Properties
of Bulk Powders

L. SVAROVSKY
School of Studies in Powder Technology,
University of Bradford, UK

Published on behalf of the
BRITISH MATERIALS HANDLING BOARD
by
ELSEVIER APPLIED SCIENCE
LONDON and NEW YORK

kluwer
the language of science

References

- گوردون داوسون،ترجمه دکتر علی حائریان اردکانی، "متالورژی پودر"،مرکز نشر دانشگاهی تهران،۱۳۷۲.
عنوان اصلی:
Powder Metallurgy,the process and its products

- ارهارد کلار،ترجمه دکتر علی حائریان، "متالورژی پودر"، موسسه چاپ و انتشارات آستان قدس رضوی،۱۳۶۷.

- راندال ژرمن،ترجمه دکتر مجتبی ناصریان، "متالورژی پودر"، نشر میعاد،مرکز پژوهش های متالورژی پودر لوت،۱۳۷۵.

References

ipmd.net

POWDER METALLURGY REVIEW

E-newsletter

www.epma.com

www.mpif.org

http://www.epma.com/

Login | Contact Us | Sitemap |

EPMA
european powder metallurgy association

Home | About Us | Membership | Powder Metallurgy | Publications | News | Events | Activities | Projects | Sectoral & Working Gro

Publications shop now open. Wide range of PM books, Euro PM Proceedings, abstracts, free publications and downloadable PDF papers. Secure online payment.

Read more >

World PM2016 Congres Exhibition

Publications

EPMA Membership

What is Powder Metallu

European Powder Metallurgy Association

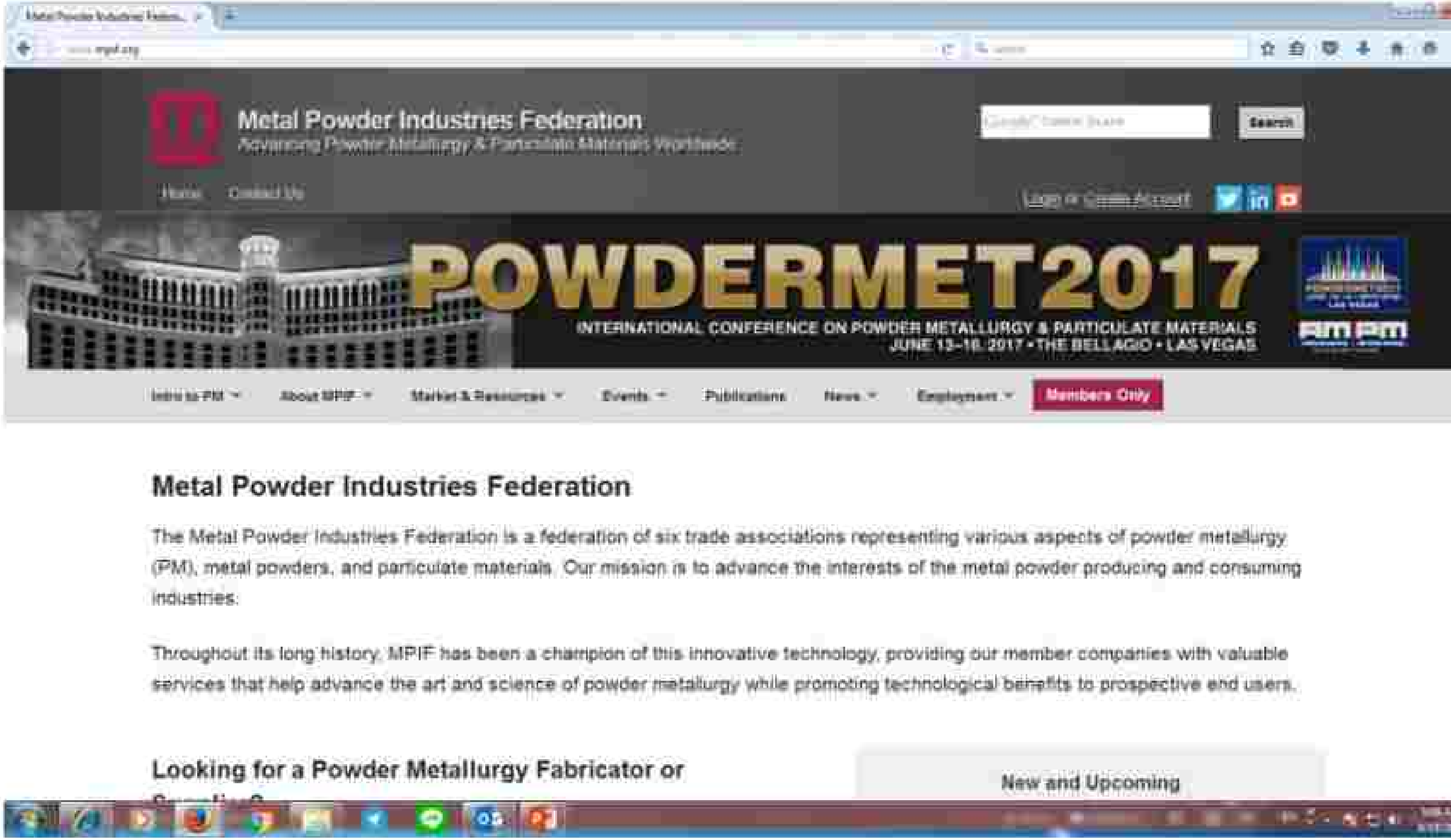
Welcome to the European Powder Metallurgy Association (EPMA) Website. This website contains a wealth of knowledge on the Powder Metallurgy manufacturing process, as well as case studies, publications and details on industry related projects and events.

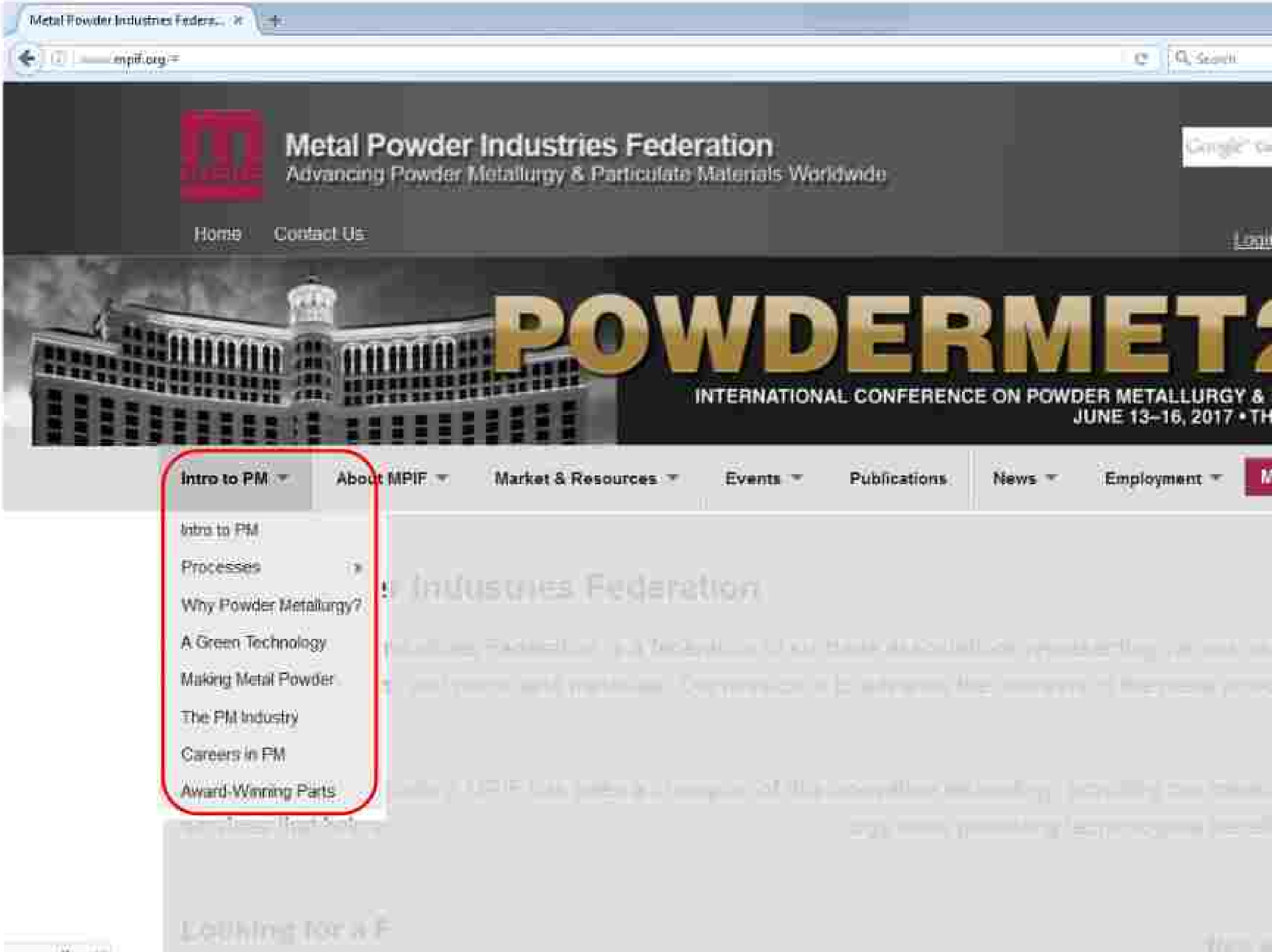
The Members Directory is one of the only online databases of Powder Metallurgy Companies and Research Centres located around Europe.

We at the EPMA serve all types of member organisations, from component metal powder and

INTRODUCTIO
TO ADDITIVE
MANUFACTURI
TECHNOLOGY


MPIF: All You Need to Kno...
mpif.org
METAL POWDER INDUSTRIES FEDERATION
MPIF
Advancing Powder Metallurgy & Particulate Materials Worldwide
HOME
SITE MAP
SEARCH
CALENDAR
CONTACT US
Currently not logged in
Sunday, September 13, 2015
ACCOUNT LOGIN
Introducing PM
About MPIF
PM Design Center
Directory of PM Fabricators & Suppliers
How to Reach the PM Market
Conferences & Exhibits
Seminars & E-learning
Online Registration for All Events
Publications
Working in PM
Welcome to the world's most comprehensive source for powder metallurgy and particulate materials knowledge: the place to visit in order to keep up with the latest advances in this exciting technology and industry.
PICK PM
New to the world of powder metallurgy and particulate materials? START HERE to learn all about it.
POWDERMET2016
JUNE 5-8 • MPIF/APMI
BOSTON
It's Not Too Late!
PM POST-SINTERING SEMINAR
September 22–23, 2015
Penn Stater Conference Center Hotel
State College, PA
PM AUTOMOTIVE
Parts Catalog
PM
A recognized green technology
Powder Metallurgy—Intrinsically Sustainable
LEARN MORE
PICK PM is a trademark of MPIF
Privacy Policy


Metal Powder Industries Federation
Home
Contact Us
Search
POWDERMET2017
INTERNATIONAL CONFERENCE ON POWDER METALLURGY & PARTICULATE MATERIALS
JUNE 13–16, 2017 • THE BELLAGIO • LAS VEGAS
Publications
News
Members Only
Metal Powder Industries Federation
The Metal Powder Industries Federation is a federation of six trade associations representing various aspects of powder metallurgy (PM), metal powders, and particulate materials. Our mission is to advance the interests of the metal powder producing and consuming industries.
Throughout its long history, MPIF has been a champion of this innovative technology, providing our member companies with valuable services that help advance the art and science of powder metallurgy while promoting technological benefits to prospective end users.
Looking for a Powder Metallurgy Fabricator or
New and Upcoming


Metal Powder Industries Federa...
mpif.org
Search
Metal Powder Industries Federation
Advancing Powder Metallurgy & Particulate Materials Worldwide
Home
Contact Us
POWDERMET2
INTERNATIONAL CONFERENCE ON POWDER METALLURGY &
JUNE 13–16, 2017 • TH
Intro to PM
About MPIF
Market & Resources
Events
Publications
News
Employment
Intro to PM
Processes
Why Powder Metallurgy?
A Green Technology
Making Metal Powder
The PM Industry
Careers in PM
Award-Winning Parts

Introducing Powder Metallurgy

A complex planetary carrier for a four-wheel drive torque transfer system. A helical gear and blades of stainless steel used in laparoscopic surgical scissors. A manifold weighing over 6.5 tons used on an offshore oil platform. A steel connecting rod used in V-8 engines.

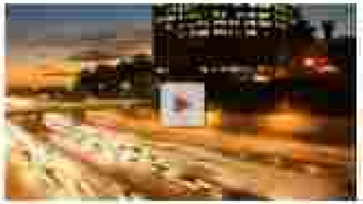
What do these diverse parts have in common? All were manufactured using a process called **powder metallurgy (PM)**.

But what is powder metallurgy? Powder metallurgy is a metal-forming process performed by heating compacted metal powders to just below their melting points. Although the process has existed for more than 100 years, over the past quarter century it has become widely recognized as a superior way of producing high-quality parts for a variety of important applications. This success is due to the advantages the process offers over other metal forming technologies such as forging and metal casting, advantages in material utilization, shape complexity, near-net-shape dimensional control, among others. These, in turn, contribute to sustainability, making

Powder metallurgy is an integral part of our lives.

To learn more about this metal-forming process watch:

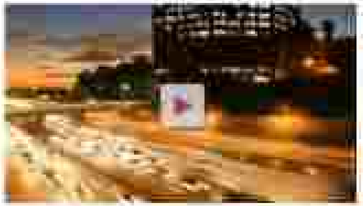
Powder Metallurgy Touches Your Life, Part 1



Powder Metallurgy: The Preferred Metal-Forming Solution, showcases the fabrication capabilities of the various technologies known collectively as powder metallurgy (PM). Built on the theme, "Every day, in some way, PM touches your life," the two-part video uses dozens of examples of actual components manufactured for many different applications to illustrate the benefits PM offers parts designers and engineers.

Powder Metallurgy Touches Your Life, Part 2

Metal Injection Molding Touching Your Life, Part 1



This video, in two parts, showcases the fabrication capabilities of the various technologies known collectively as powder metallurgy (PM), with particular focus on metal injection molding. Part 1 of the program uses dozens of examples of actual components manufactured for many different applications to illustrate the benefits all the various PM technologies offer parts designers and engineers. Part 2 of the program describes the metal injection molding process, providing design engineers with all the facts needed to understand why, if they're designing an intricate metal part, they should think of MIM from the start.

Metal Injection Molding Touching Your Life, Part 2

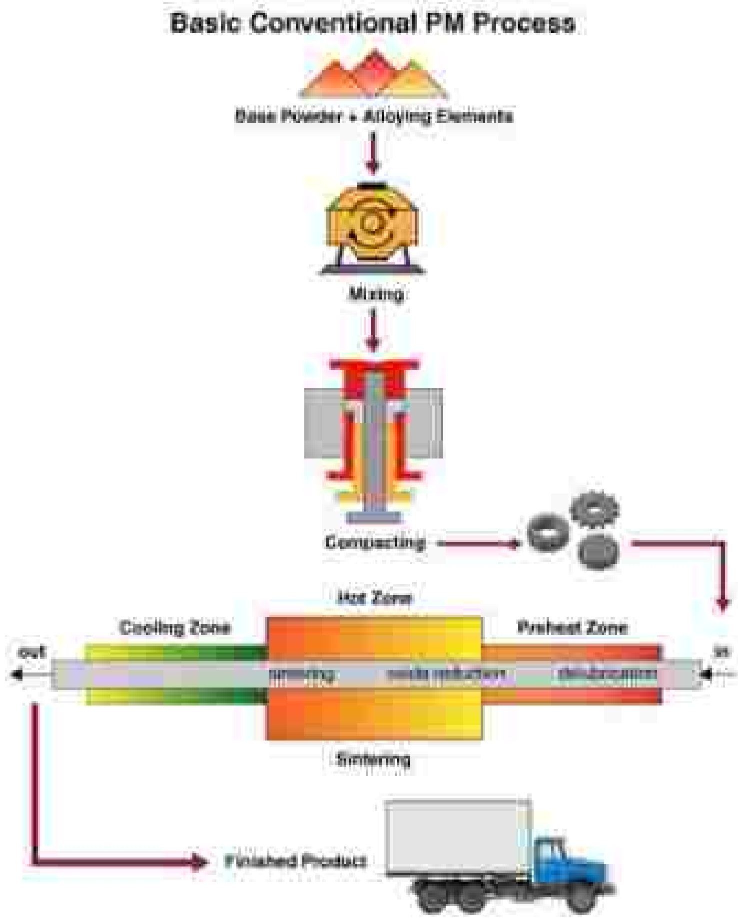
A recognized green technology

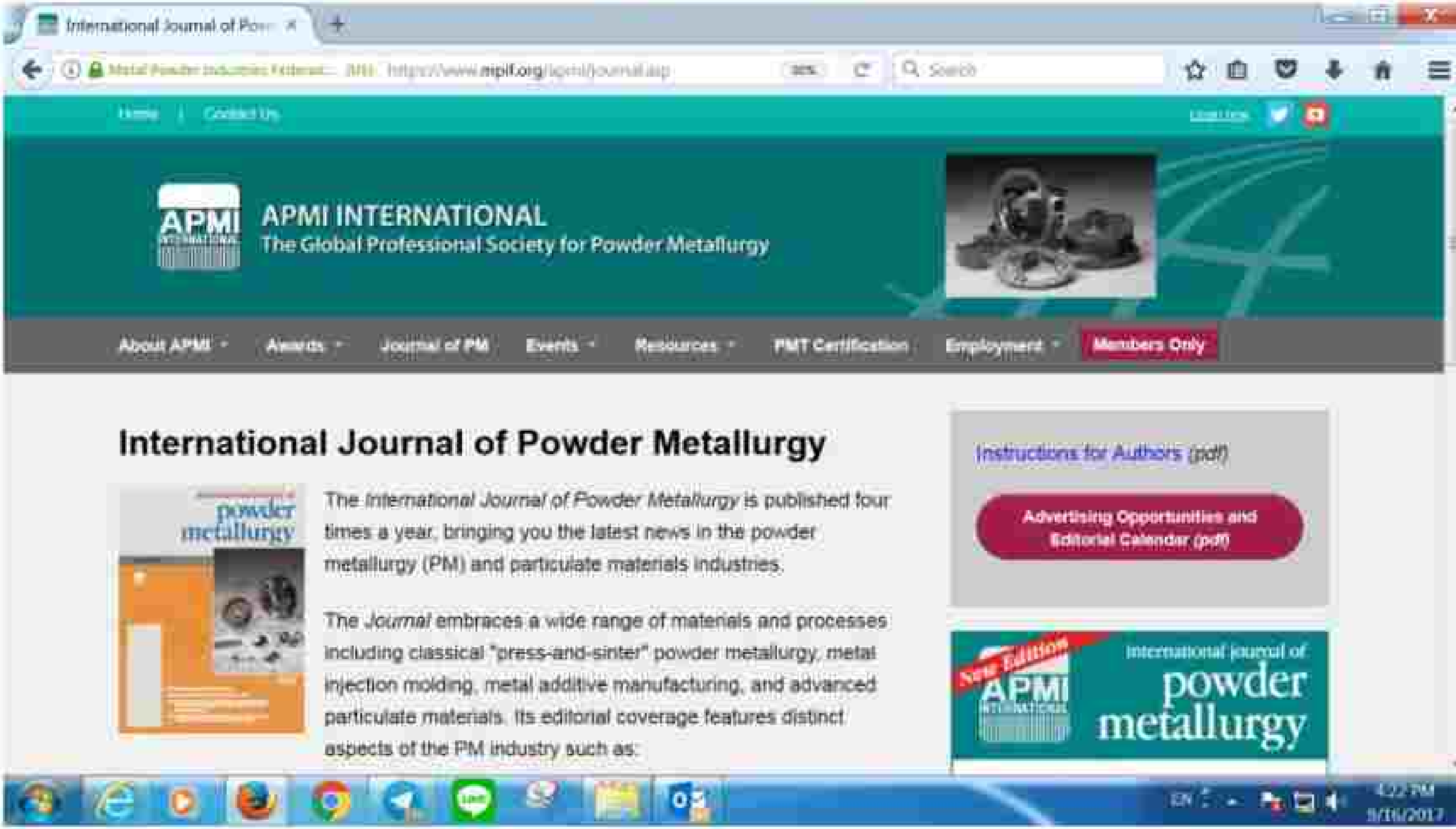
[redacted]

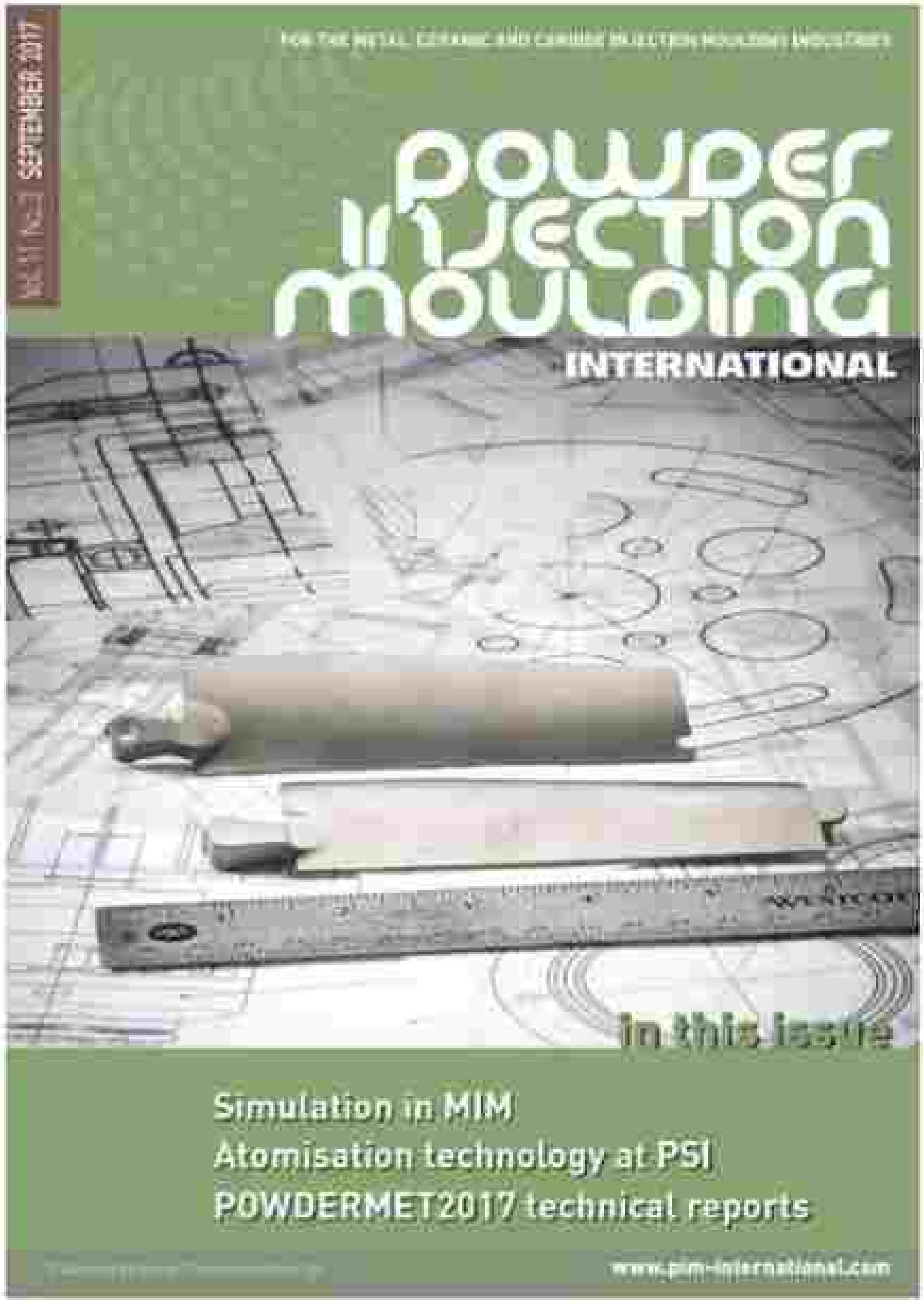
Conventional Powder Metallurgy Process

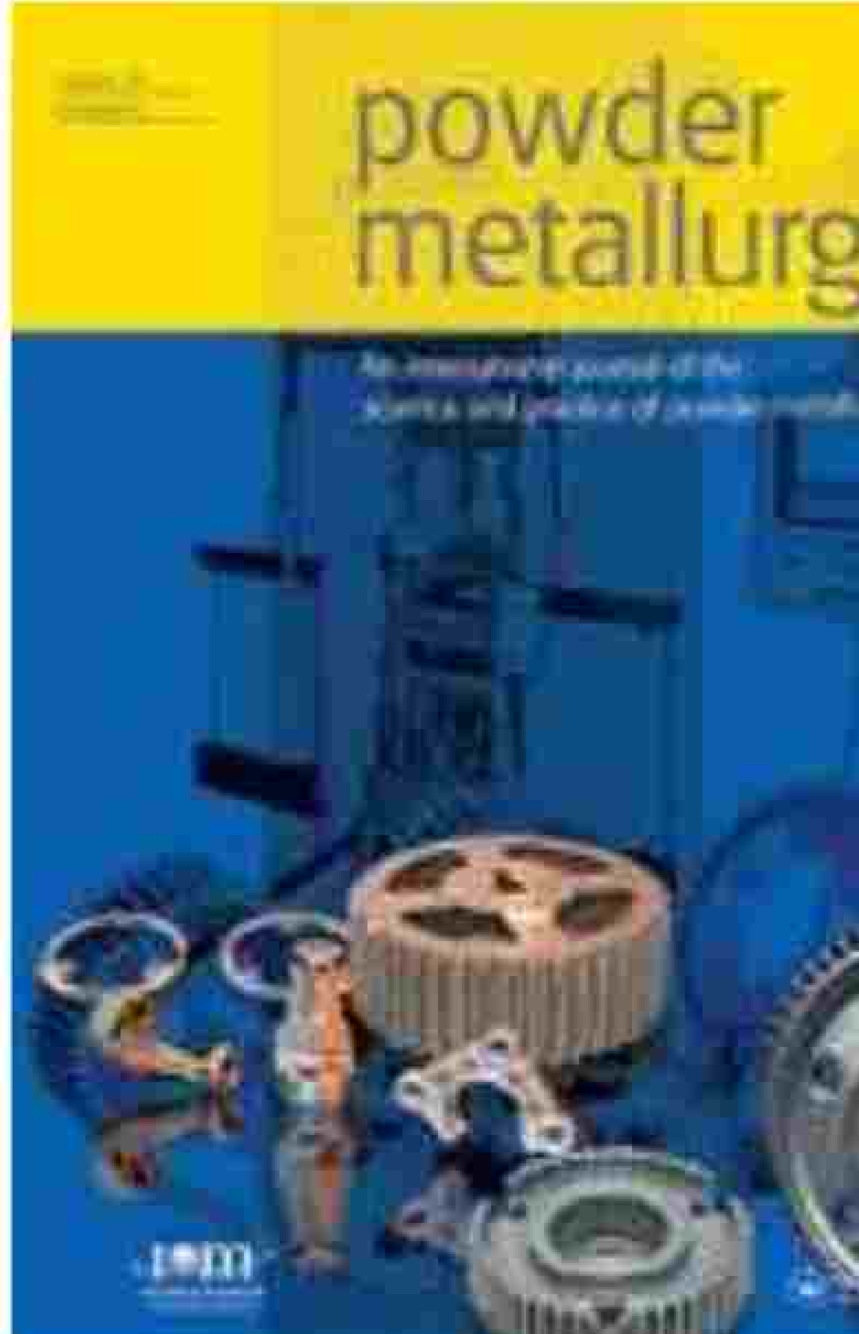
The powder metallurgy (PM) process, also known as press-and-sinter, depicted in the diagram below, consists of mixing elemental or alloy powders, compacting the mixture in a die, and then sintering, or heating, the resultant shapes in an atmosphere-controlled furnace to bond the particles metallurgically.

Most powder metallurgy parts weigh less than 5 pounds (2.27 kg), although parts weighing as much as 35 pounds (15.89 kg) can be fabricated in conventional PM equipment. While many of the early PM parts, such as bushings and bearings, were very simple shapes, today's sophisticated powder metallurgy process produces components with complex contours and multiple levels, and does so quite economically.




International Journal of Pow
Home | Contact Us
APMI INTERNATIONAL
The Global Professional Society for Powder Metallurgy
About APMI
Awards
Journal of PM
Events
Resources
PMT Certification
Employment
Members Only
International Journal of Powder Metallurgy
powder metallurgy
The International Journal of Powder Metallurgy is published four times a year, bringing you the latest news in the powder metallurgy (PM) and particulate materials industries.
The Journal embraces a wide range of materials and processes including classical "press-and-sinter" powder metallurgy, metal injection molding, metal additive manufacturing, and advanced particulate materials. Its editorial coverage features distinct aspects of the PM industry such as:
Instructions for Authors (pdf)
Advertising Opportunities and Editorial Calendar (pdf)
New Edition
APMI INTERNATIONAL
international journal of
powder metallurgy


SEPTEMBER 2017
FOR THE METAL, CERAMIC AND CARBIDE INJECTION MOULDING INDUSTRIES
powder injection moulding
INTERNATIONAL
in this issue
Simulation in MIM
Atomisation technology at PSI
POWDERMET2017 technical reports
www.pim-international.com


powder
metallurg

VOL. 6 NO. 3 AUTUMN/FALL 2017

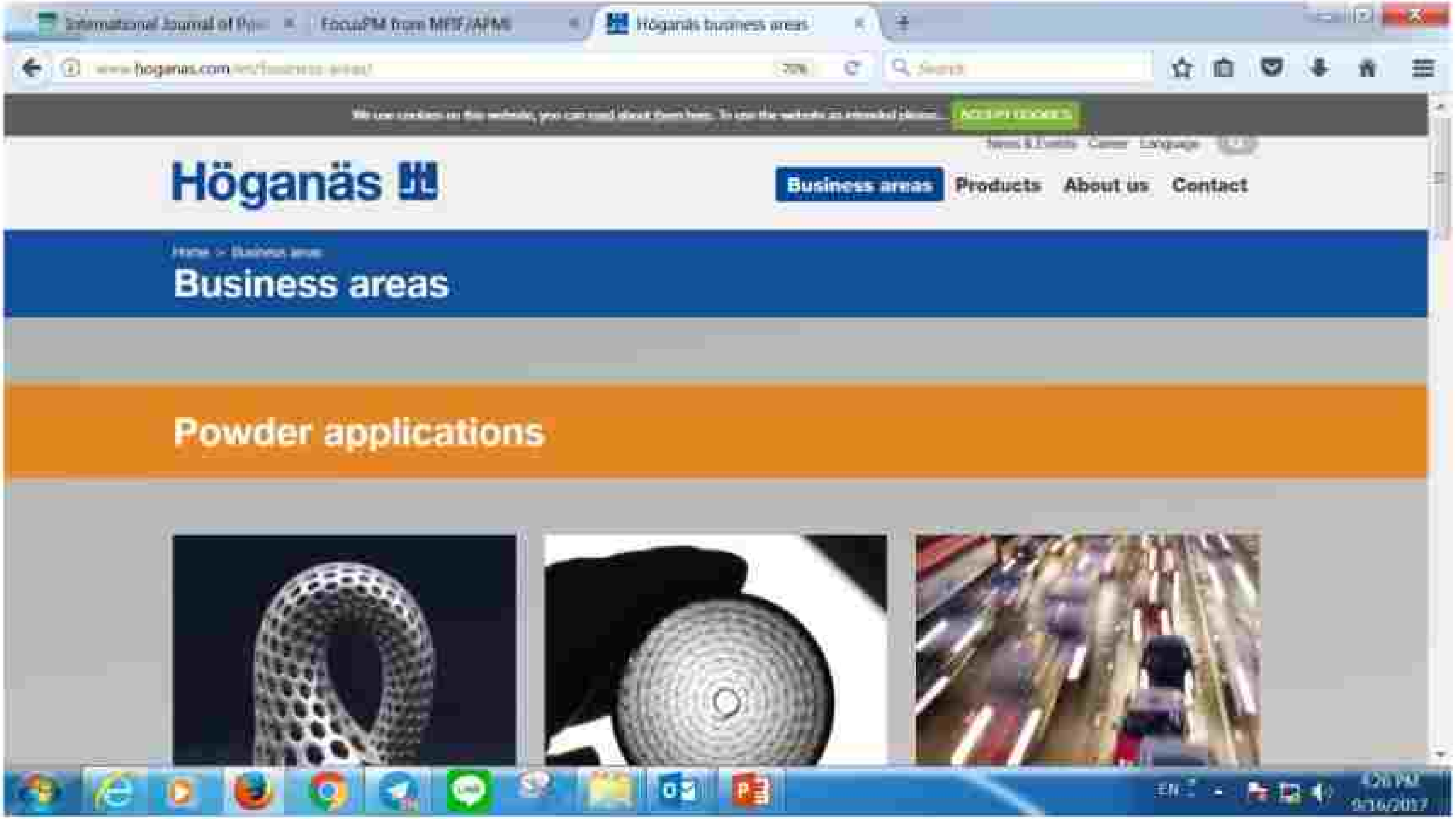
POWDER METALLURGY REVIEW

SUMITOMO ELECTRIC INDUSTRIES

REFRACTORY METALS & HARD MATERIALS

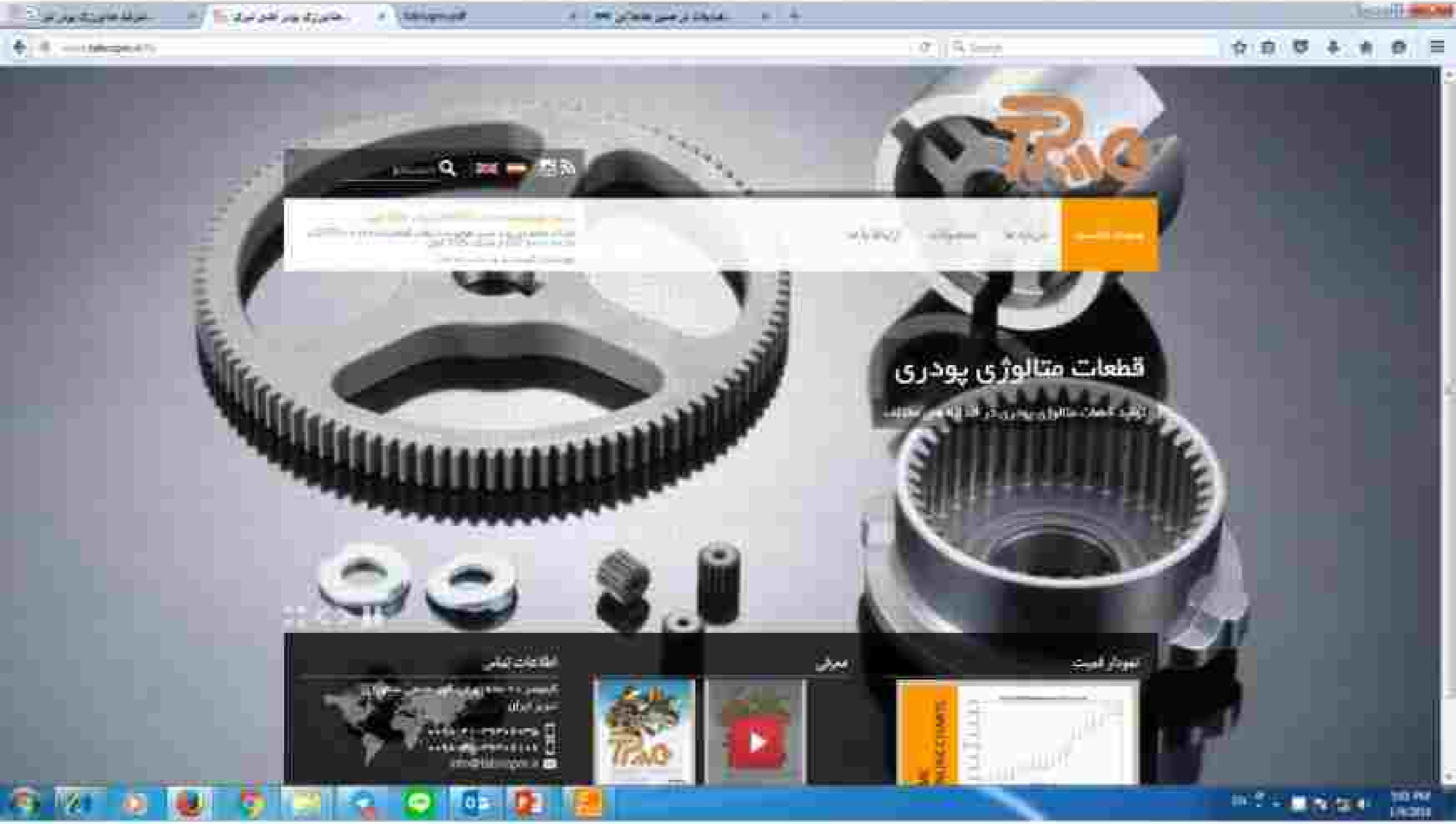
LIGHTWEIGHTING WITH ALUMINIUM ALLOYS

www.pm-review.com



http://www.hoganas.com/en/business-areas/


SME - Home
www.sme.org
Search
Register or Sign In | Cart | Contact
Search SME
GO
About SME
Join | Renew
Members
Events
Training & Development
Media
Education Foundation
SME Store
powder metallurgy
MFG
DAY
gold sponsor, SME
s Manufacturing Day in
y of ways
Energy Yearbook: latest trends and advancements in the industry
SME Technology Interchange at WESTEC to feature NASA
SME. We are the intersection of manufacturing technology and workforce development. Connecting people who are passionate about manufacturing and inspiring future generations.
2,000,000
MANUFACTURING JOBS
Go Unfilled
Technology that drives
MANUFACTURING
SME is addressing the skills gap
From 3D printing to emerging manufacturing


قطعات متالوژی پودری

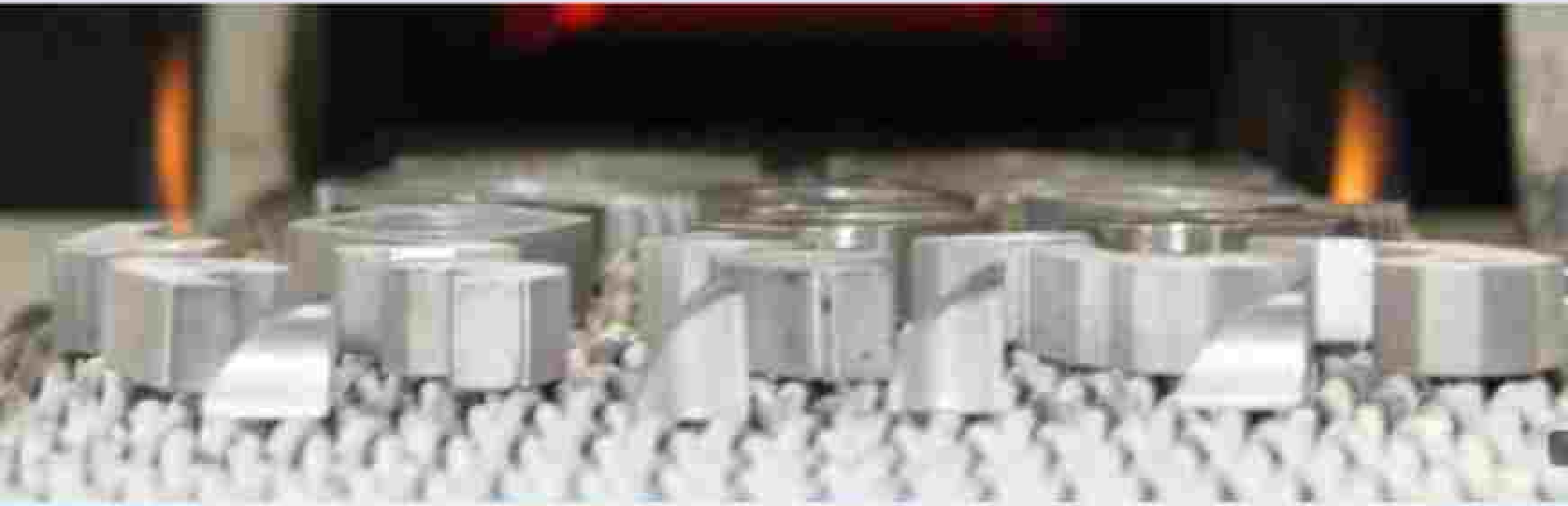
TABRIZ FERROUS
POWDER
METALLURGY
COMPANY

RWTUV

متالورژی پودر آهنی تبریز

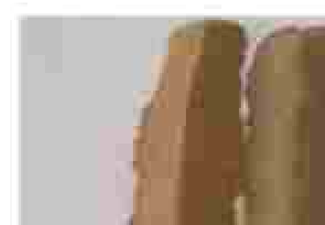

FERROUS POWDER METALLURGY COMPANY

Mecomex.com
ورود
صفحه اصلی
تماس با ما
درباره ی ما
محصولات
متالوژی پودر ایتوک تبریز
پودر آلومینیوم
لیست خرید و فروش
تماس با شرکت متالوژی پودر ایتوک تبریز
تماس با شرکت متالوژی پودر ایتوک تبریز



شرکت فرآورده های متالورژی پودری سهند



early **sintered pots** were not sintered at high temperatures, so they were weak and rarely survived. They leaked liquids because of their porosity.
By approximately 10,000 BC, fired clay vessels were used for water storage, indicating techniques for sealing surface pores had been mastered.

Figure 2.5 Early Chinese porcelain production excelled in reaching high sintering temperatures by
use of sloped dragon kiln design, sketched in this early illustration.

European porcelain eventually found composition formulations and sintering techniques
capable of forming high value products, initially near Dresden.

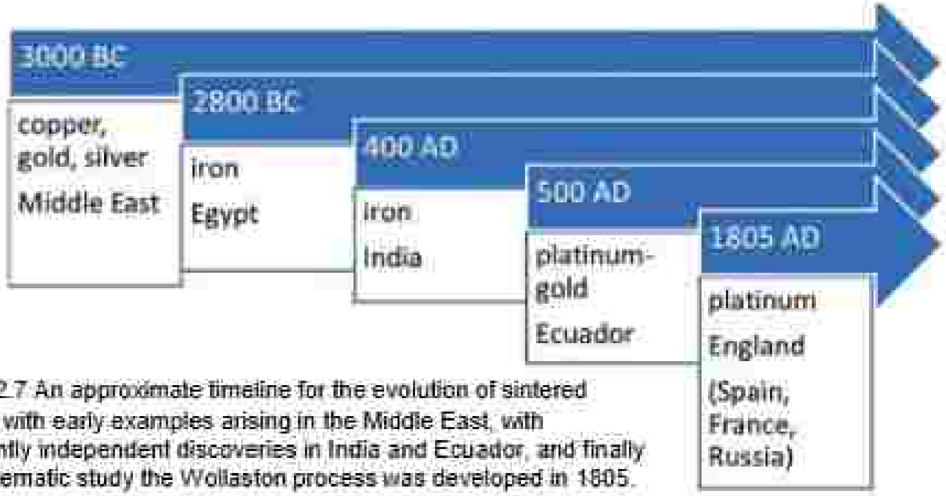
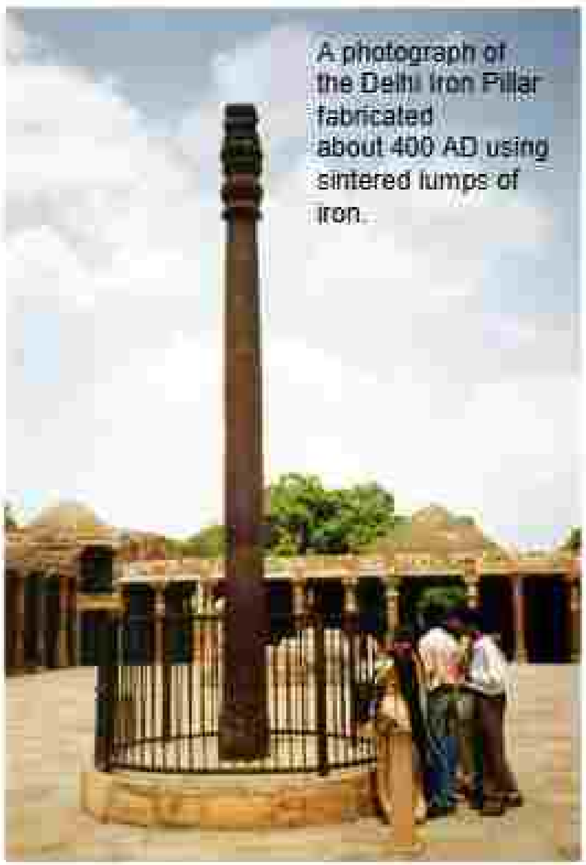


Figure 2.7 An approximate timeline for the evolution of sintered metals, with early examples arising in the Middle East, with apparently independent discoveries in India and Ecuador, and finally via systematic study the Wollaston process was developed in 1805.

The first of these are from approximately 3000 BC [4,5].
Most of these easily reduced metals were sintered long ago.



A photograph of the Delhi Iron Pillar fabricated about 400 AD using sintered lumps of iron.

Platinum Crucibles

Figure 2.10 Photograph of an early sintered gold-platinum decorative medallion.

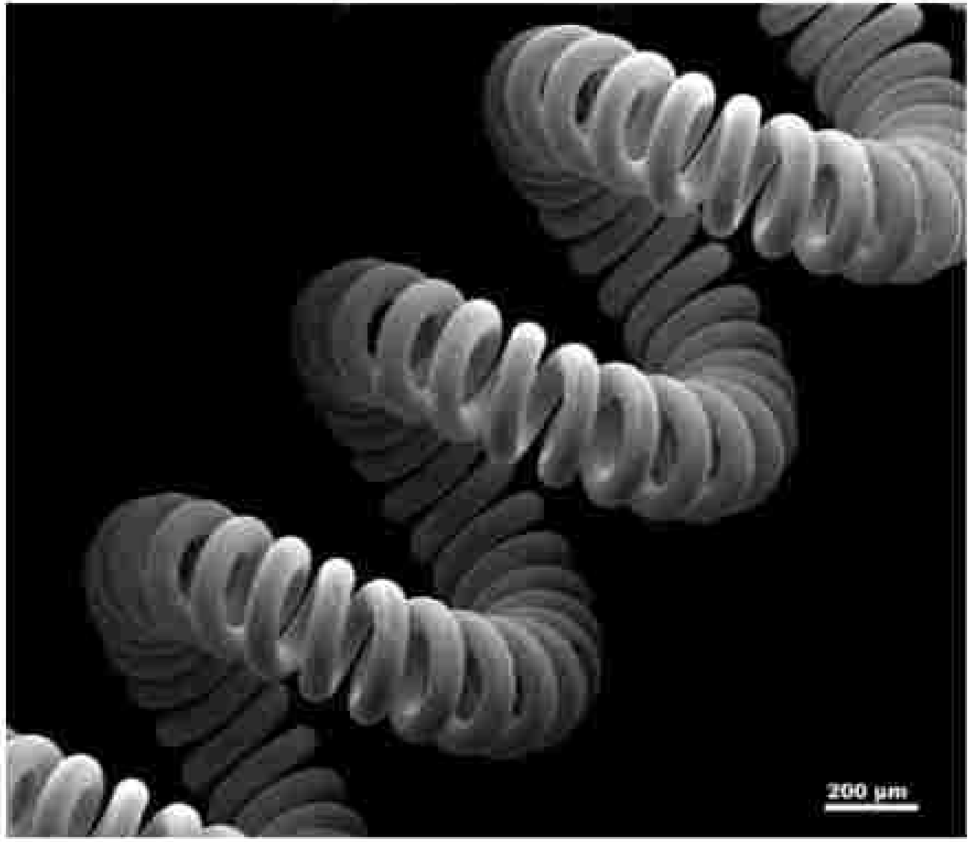
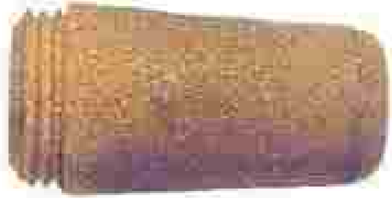


Figure 2.16 This is a scanning electron micrograph of a coiled tungsten lamp filament.





متالورژی پودر علم نوینی است که توسعه آن از مسیری بسیارابهام انگیز گذشته است.

متالورژی پودرشیوه ای است نوین برای شکل دهی فلزات.

متالورژی پودر نه یک هنر،بلکه تکنولوژی موفقی است که در خط مقدم تکوین مفاهیم تازه مهندسی مواد و شیوه های نوین شکل دهی فلزات جای دارد.

فرایند تبدیل پودربه قطعه را می توان از جنبه های تکنولوژیکی و یا علمی مورد توجه قرار داد.

در حالت اول (جنبه تکنولوژیکی) تکیه بر روش تولید مواد و قطعات خاص است.

در حالیکه از جنبه علمی،متالورژی پودر به منزله ترکیبی از قوانین پایه ای ترمودینامیک، مکانیک و سینتیک تلقی می گردد

در این تکنولوژی نه تنها شیمی ماده بلکه موارد زیر قابل کنترل می باشد :

- پارامترهای عملیات حرارتی
- پارامترهای ریزساختاری
- توزیع فازها و ریزسازهای قطعه (micro constituents) از جمله تخلخل

متالورژی پودر که معمولا با حروف اول واژه های انگلیسی آن یعنی PM یا P/M (Powder Metallurgy) مشخص می شود را می توان

"تولید فراورده های مفید از پودر فلز ،بدون گذر از حالت مذاب" تعریف کرد.

در این مبحث فرایندهای
تولید پودر و رفتار پودر در مراحل فشردن بعدی تاثیر گذارند
که به نحو چشمگیری کل فرایند تولید را تحت تاثیر قرار می دهد.

فعالیت های متالورژی پودر

تعریف پودر:

در این مرحله بجاست که سوال کنیم "منظور از پودرچیست؟"

یک پاسخ اولیه ممکن است این باشد که البته همه می دانند پودر چیست؟

اما این سوال واقعا به این سادگی نیست.
آیا مجموعه ساچمه هایی به قطر 5mm پودر است؟
البته که نیست؛پس مرز کجاست؟

تعریف پودر:

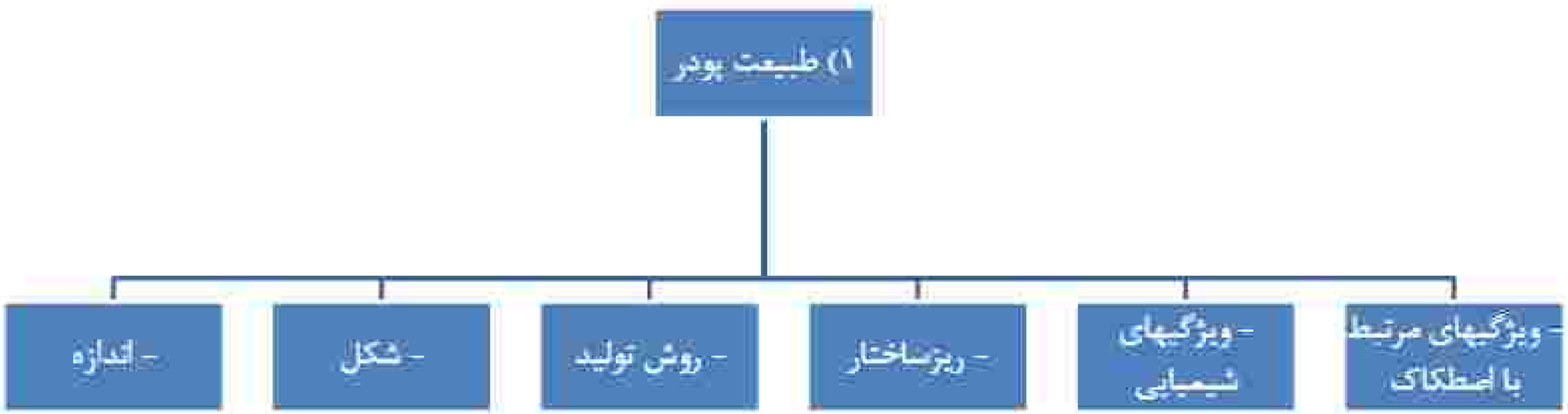
یک تعریف قابل قبول:

پودر عبارتست از دانه های ریزیک جامد که بزرگترین بعد آنها از 1mm کوچکتر باشد. (ISO 3252)

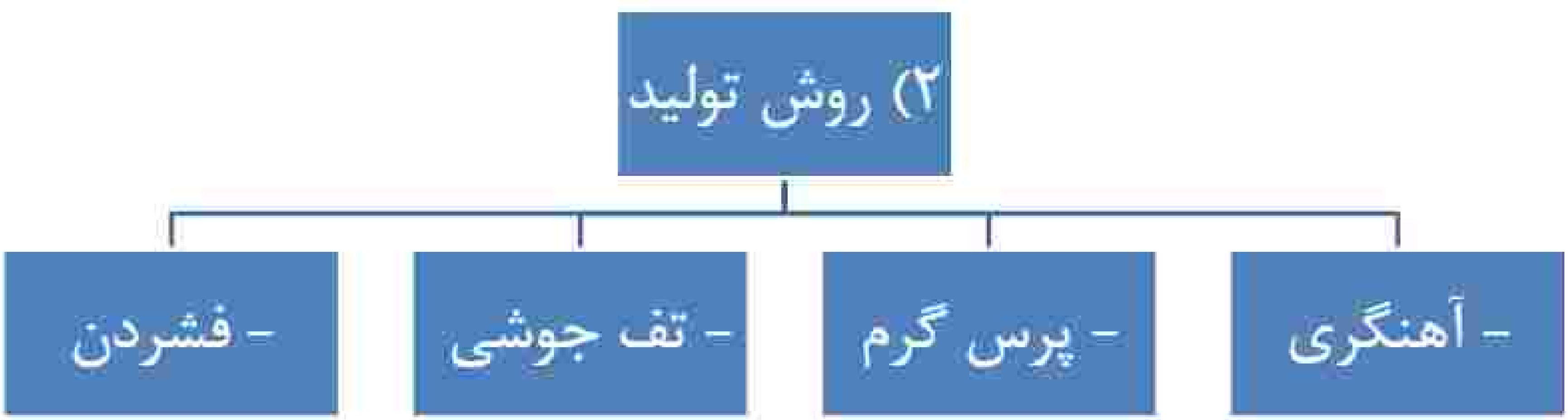
در بیشتر موارد پودرها فلزی می باشند
ولی در مواردی با فازهای دیگر هم چون سرامیک ها و پلی مرها
نیز مخلوط می شوند.

یکی از ویژگی های مهم پودر، بزرگی $\frac{Surface\ Area}{Volume}$ می باشد.

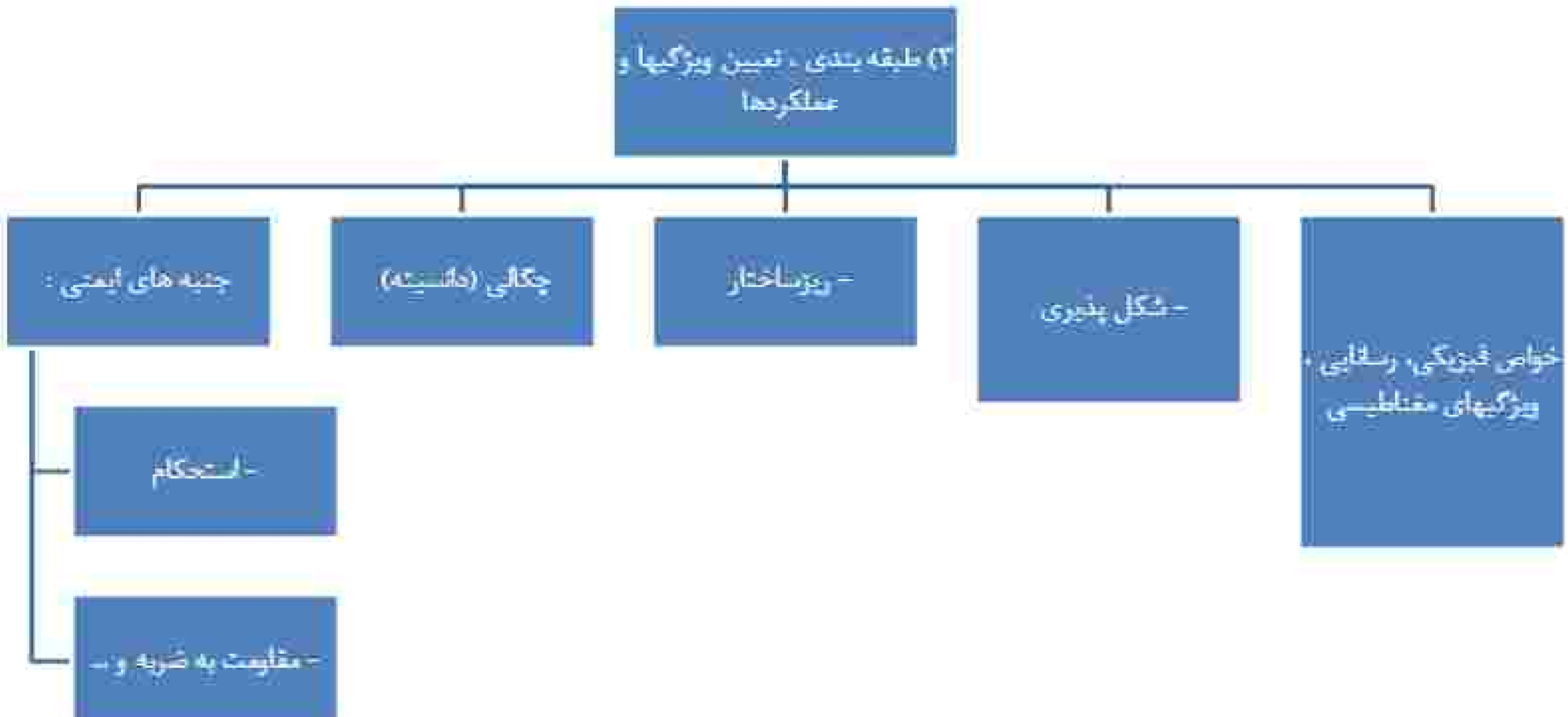
تقسیم بندی فعالیت های متالورژی پودر (تکنولوژی پودر)



تقسیم بندی فعالیت های متالورژی پودر (تکنولوژی پودر)

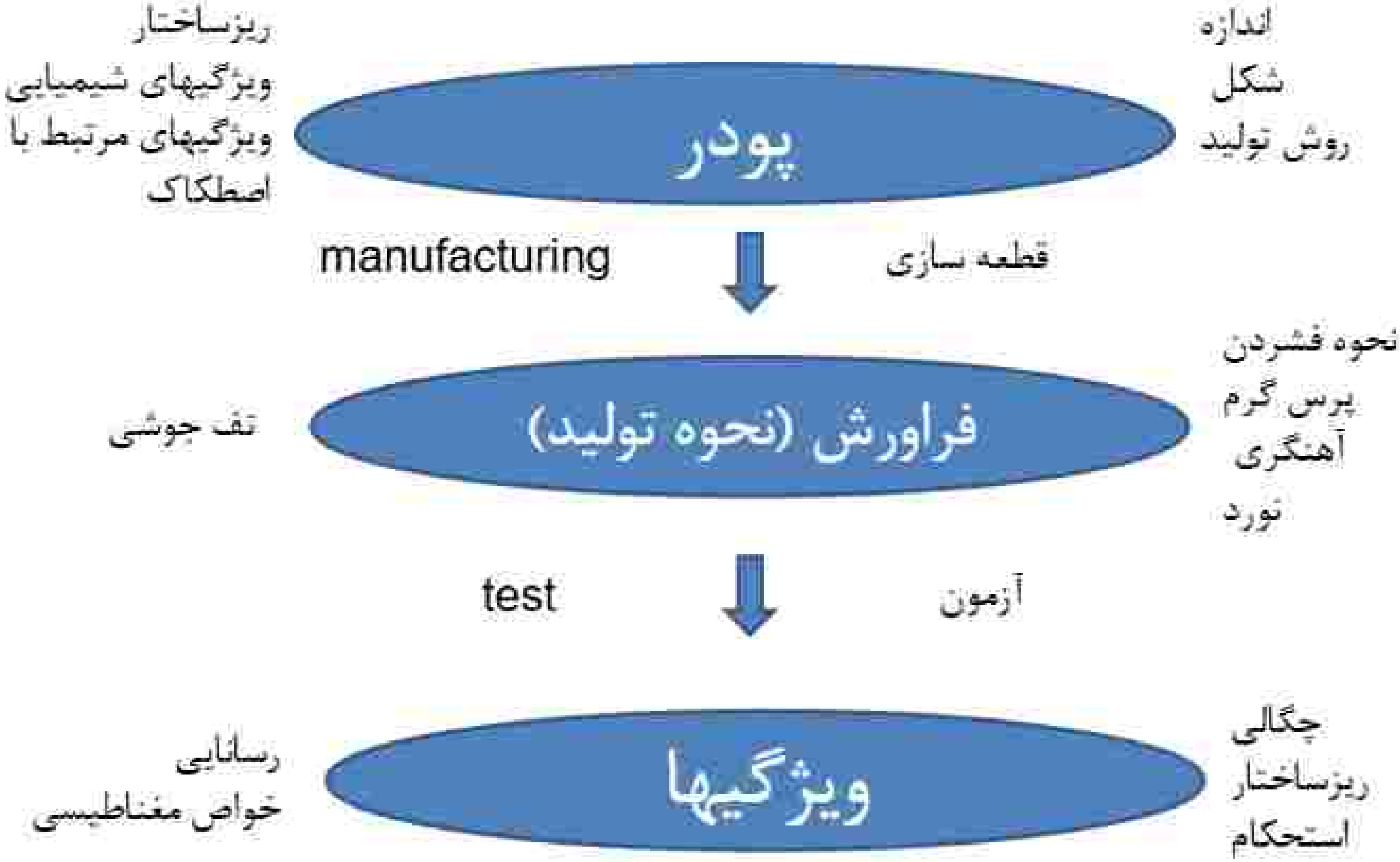


تقسیم بندی فعالیت های متالورژی پودر
(تکنولوژی پودر)



- ۴)بسته بندی و انتقال آن

تکنولوژی پودر

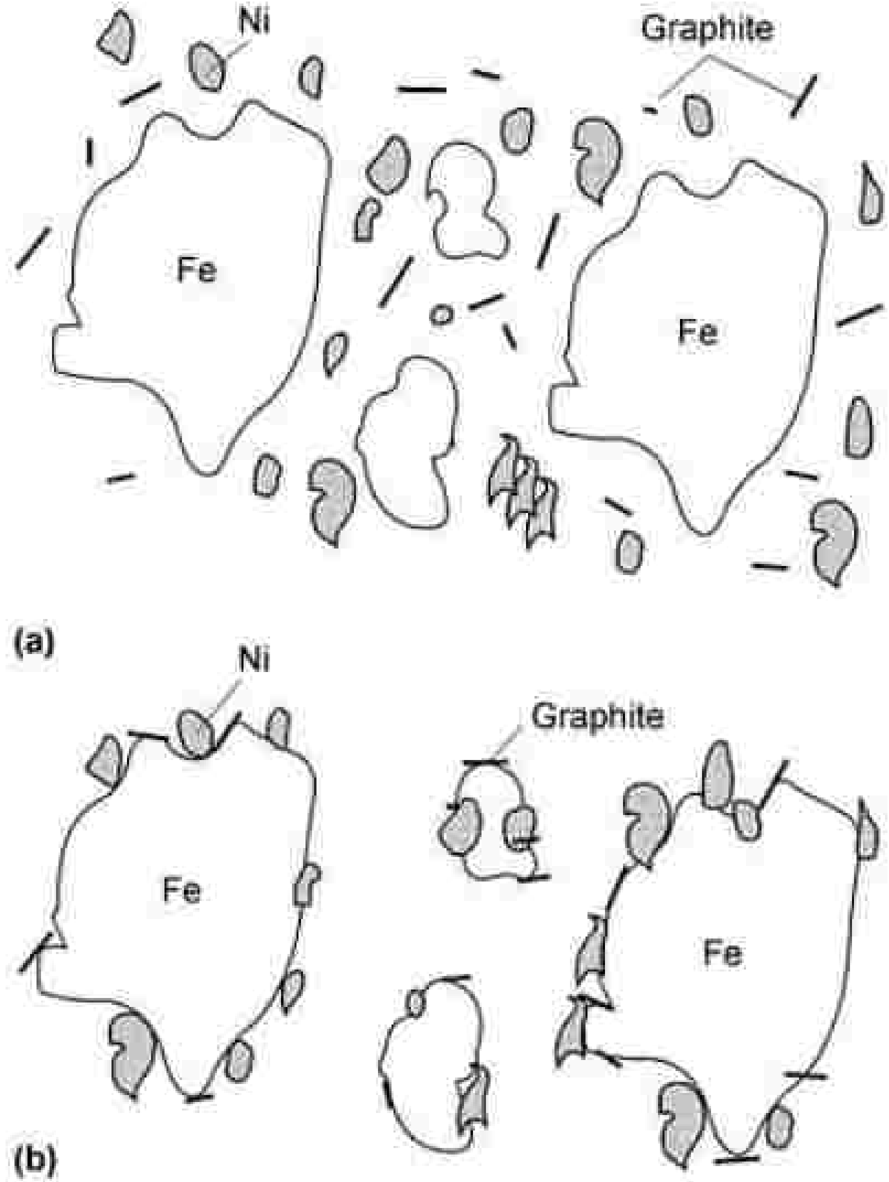


Introduction

Powder Metallurgy Process

Major Historical Developments in Powder Metallurgy

Date	Description	Origin
3000 BC	"Sponge iron" for making tools	Egypt, Africa, India
AD 1200	Cementing platinum grains	South America
1781	Fusible platinum-arsenic alloy	France, Germany
1790	Production of platinum-arsenic chemical vessels commercially	France
1822	Platinum powder formed into solid ingot	France
1826	High-temperature sintering of platinum powder compacts on a commercial basis	Russia
1829	Wollaston method of producing compact platinum from platinum sponge (basis of modern P/M technique)	England
1830	Sintering compacts of various metals	Europe
1859	Platinum fusion process	
1870	Patent for bearing materials made from metal powders self-lubricating bearings	United States
1878-1900	Incandescent lamp filaments	United States
1915-1930	Cemented carbides	Germany
Early 1900s	Composite metals	United States
	Porous metals and metallic filters	United States
1920s	Self-lubricating bearings (used commercially)	United States
1940s	Iron powder technology	Central Europe
1950s and 1960s	P/M wrought and dispersion-strengthened products, including P/M forgings	United States
1970s	Hot isostatic pressing, P/M tool steels and superplastic superalloys	United States
1980s	Rapid solidification and powder injection molding technology	United States
1990s	Intermetallics, metal-matrix composites, spray forming, nanoscale powders and warm compaction	United States, England



Alloy distribution.
(a) Regular premix.
(b) Segregation-free premix with powder binder

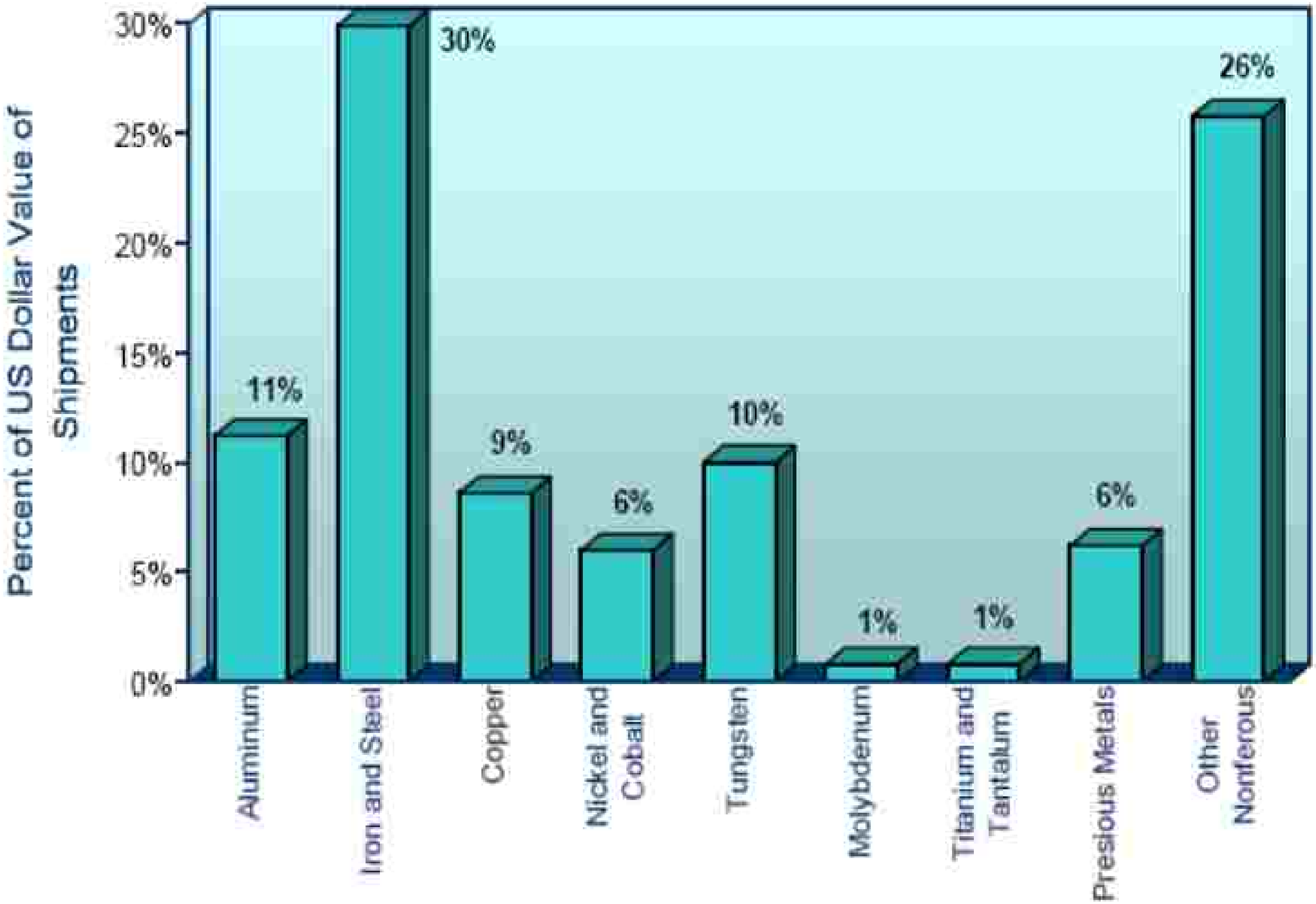


Fig. Value of 1997 US Metal Powder Shipments

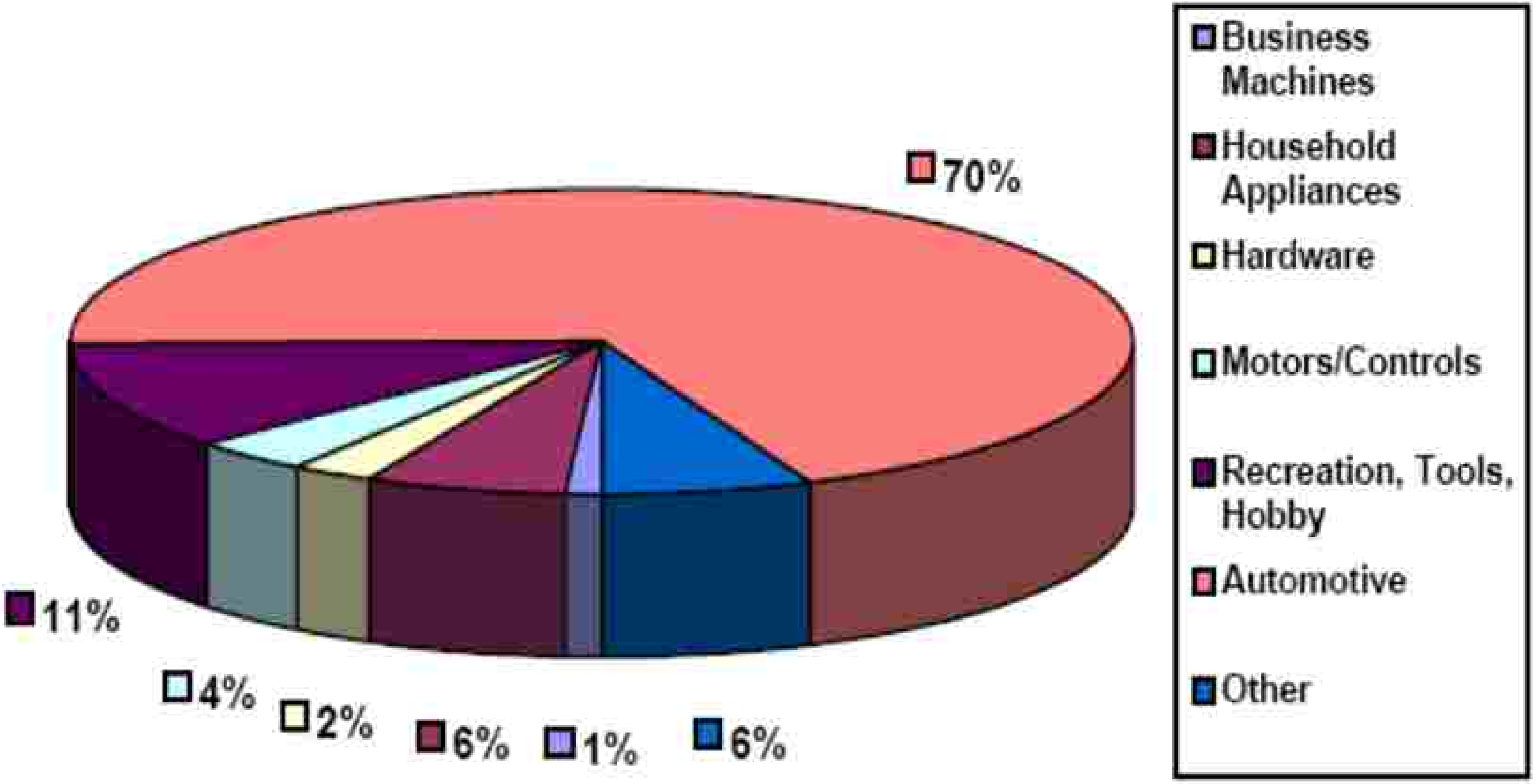
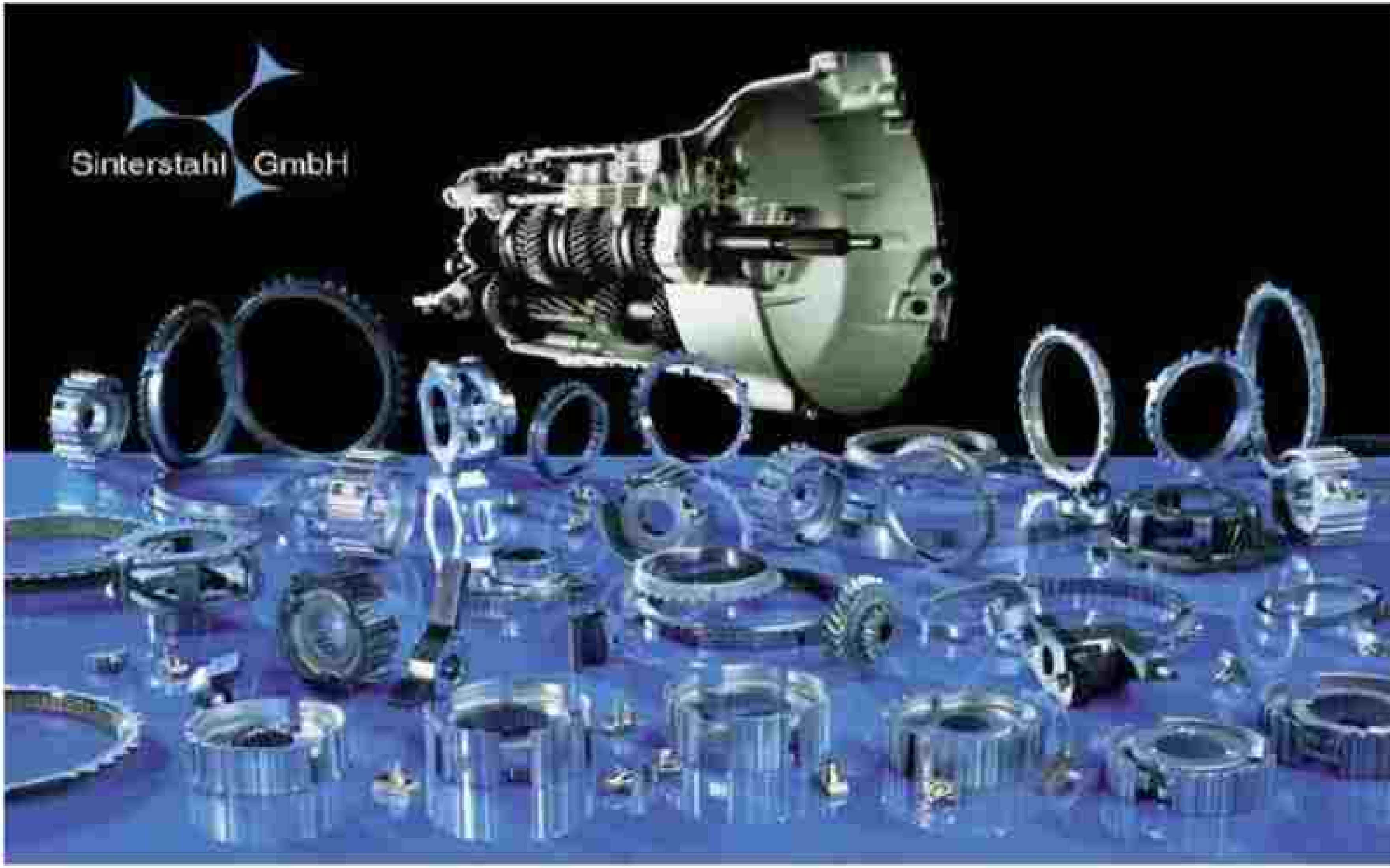
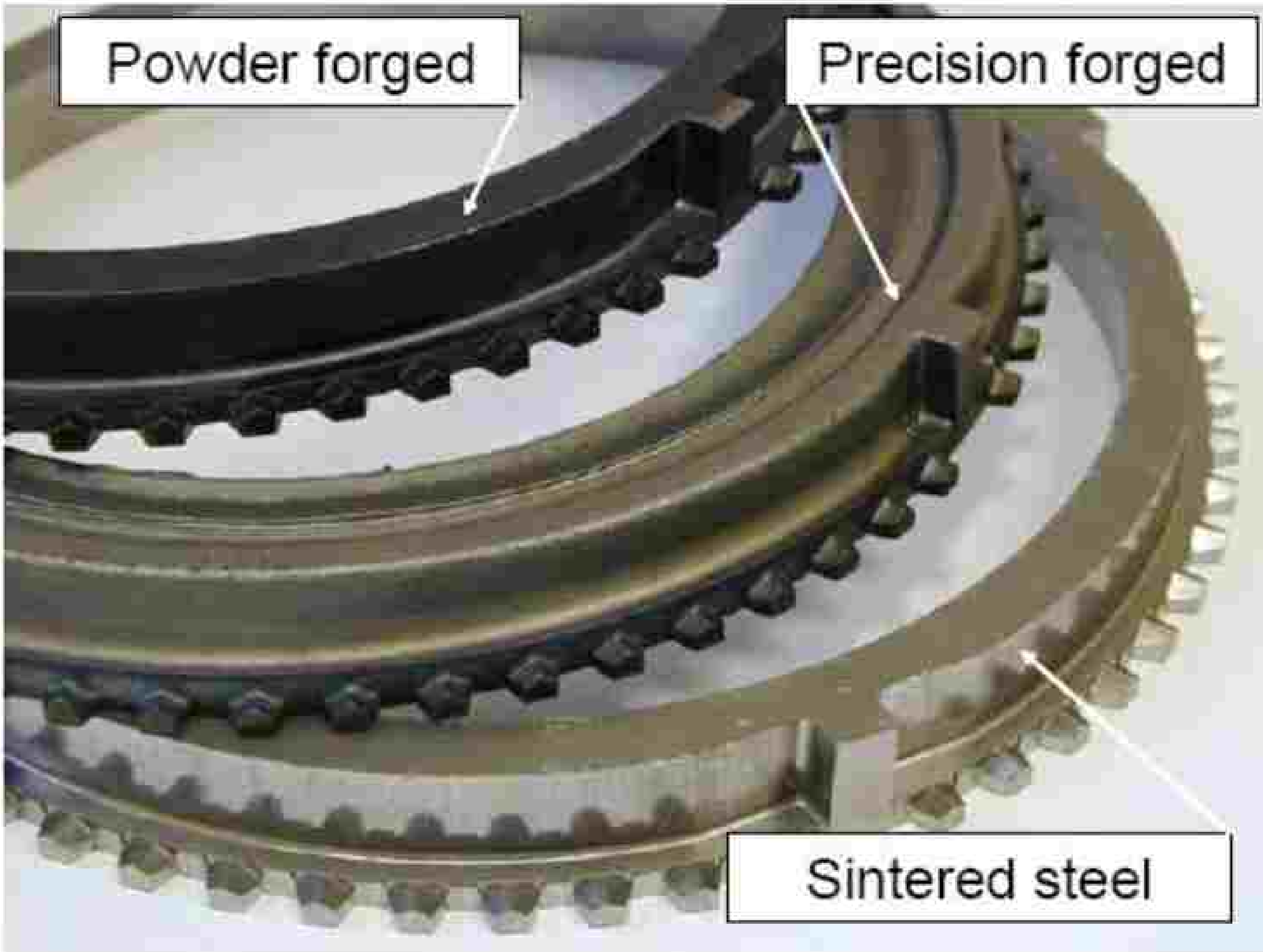


Fig. End Use of Application for Metal Powder


Sinterstahl GmbH



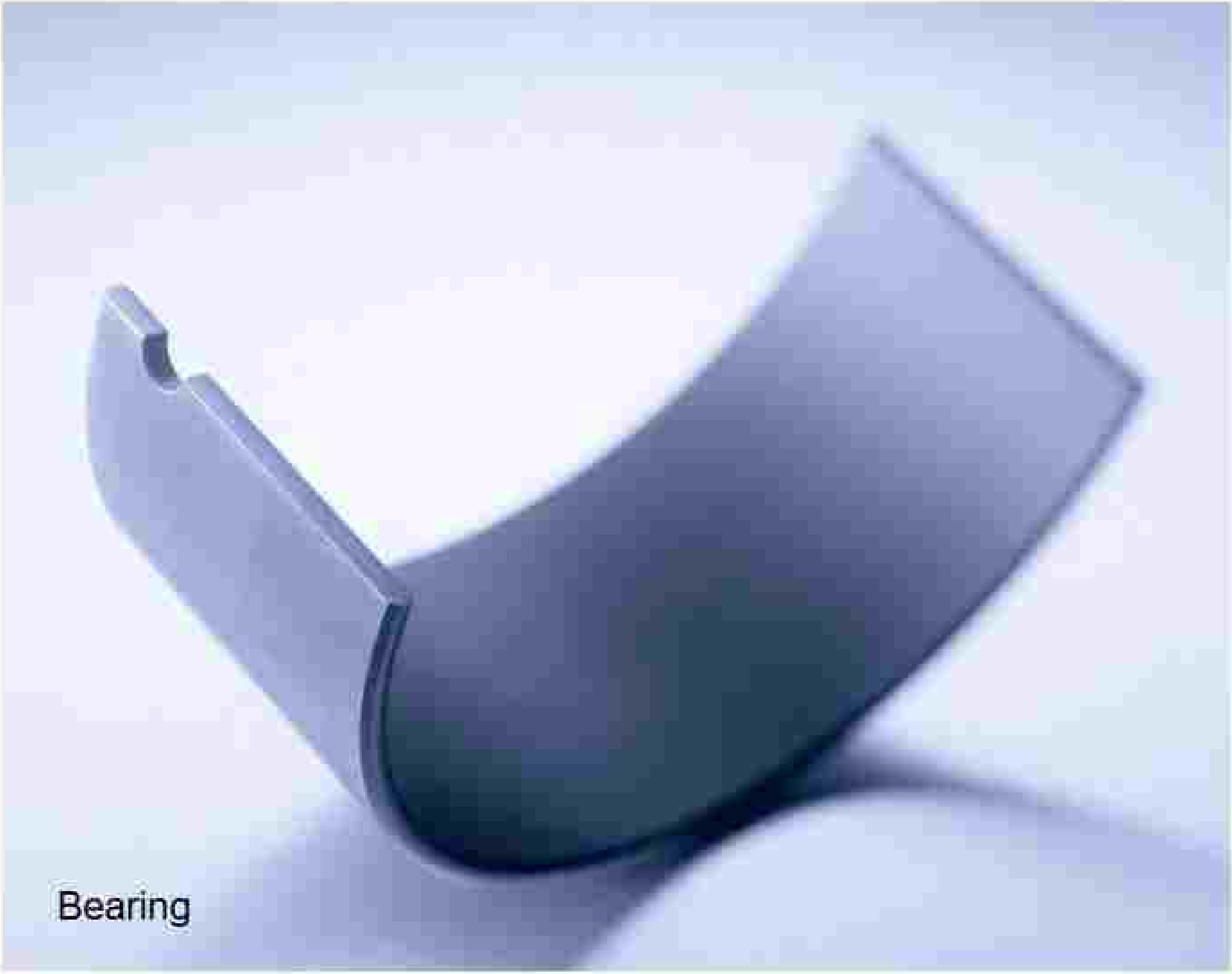

Powder forged
Precision forged
Sintered steel

متالورژي پودر در صنعت خودرو

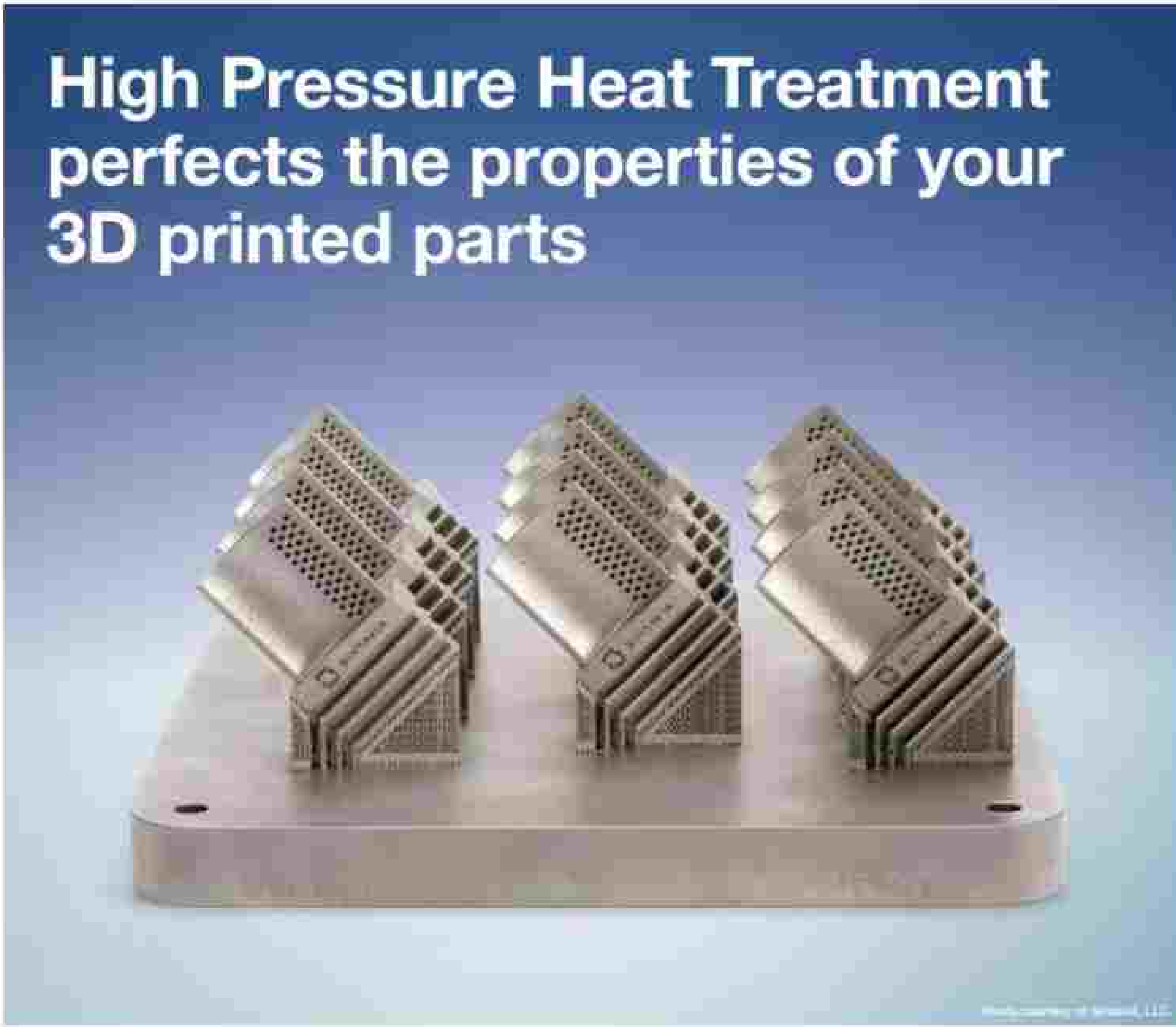
متالورژی پودر در صنعت خودروسازی

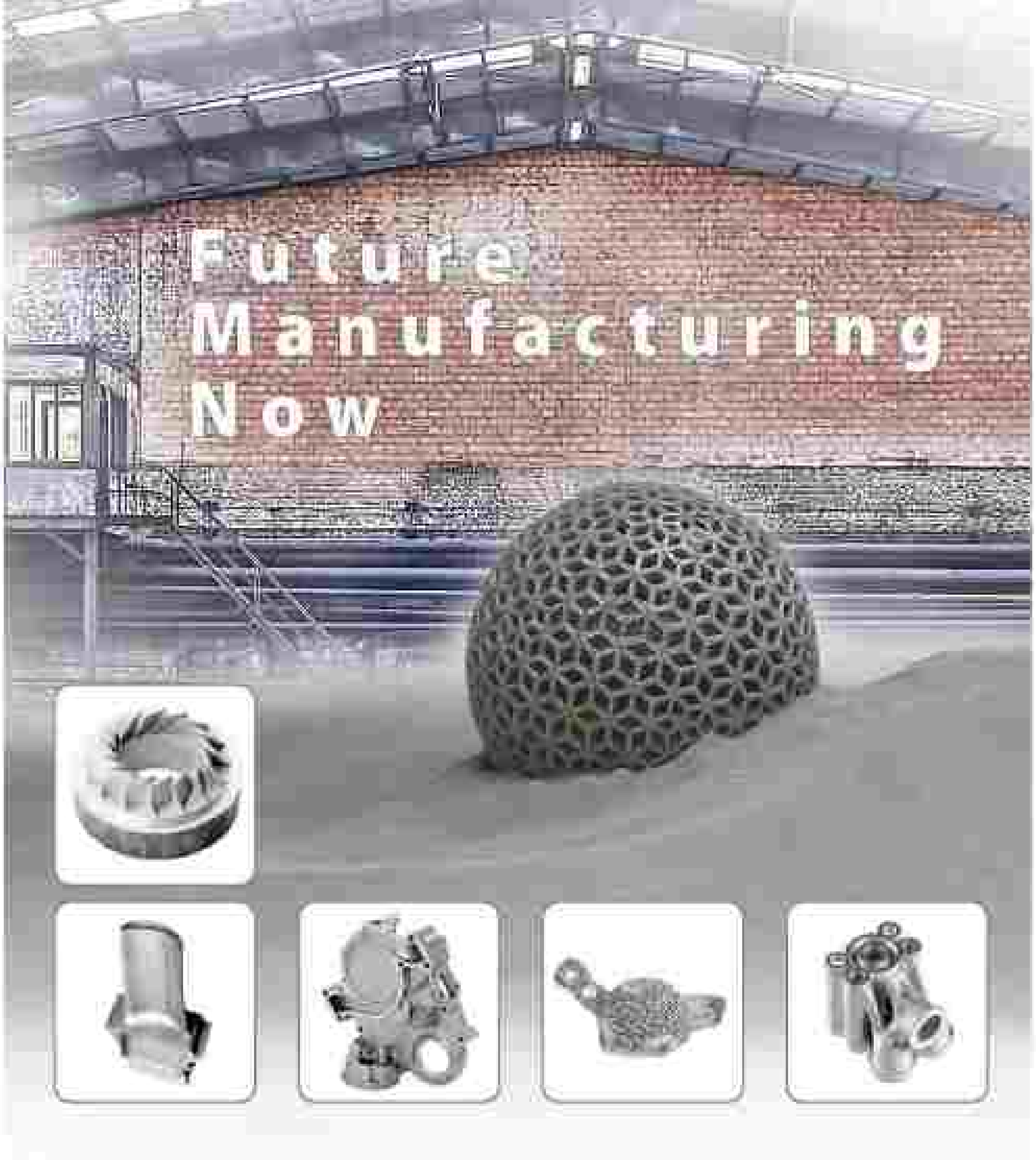
http://www.miba.com/images/press/Friction-01_Small.jpg

http://www.miba.com/images/press/Kolbenbolzen_Print.jpg



http://www.miba.com/images/press/Plain_bearing_shell_Small.jpg


High Pressure Heat Treatment perfects the properties of your 3D printed parts


Future
Manufacturing
Now

CALL FOR PRESENTATIONS

AMPM

Additive Manufacturing | With Powder Metallurgy

June 17–19, 2018 • San Antonio, Texas

Focusing on metal additive manufacturing, this conference will feature worldwide industry experts presenting the latest technology developments in this fast-growing field.

PERSPECTIVES FROM:

- End Users
- Toll Providers
- Metal Powder Producers
- Equipment Manufacturers
- R&D from Academia and Consortia

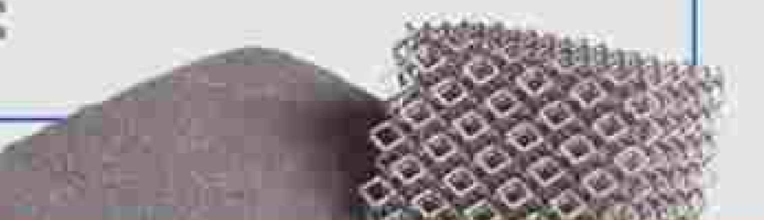
EXHIBITION:

- Trade Show Featuring Leading AMPM Suppliers

TOPICS WILL COVER:

- Materials
- Applications
- Technical Barriers
- Process Economics
- New Developments

Manuscripts are optional; however, all submitted manuscripts will be considered for the Best AMPM2018 Paper Award.



Held in conjunction with

POWDERMET2018

Submit abstracts at AMPM2018.org before November 3, 2017

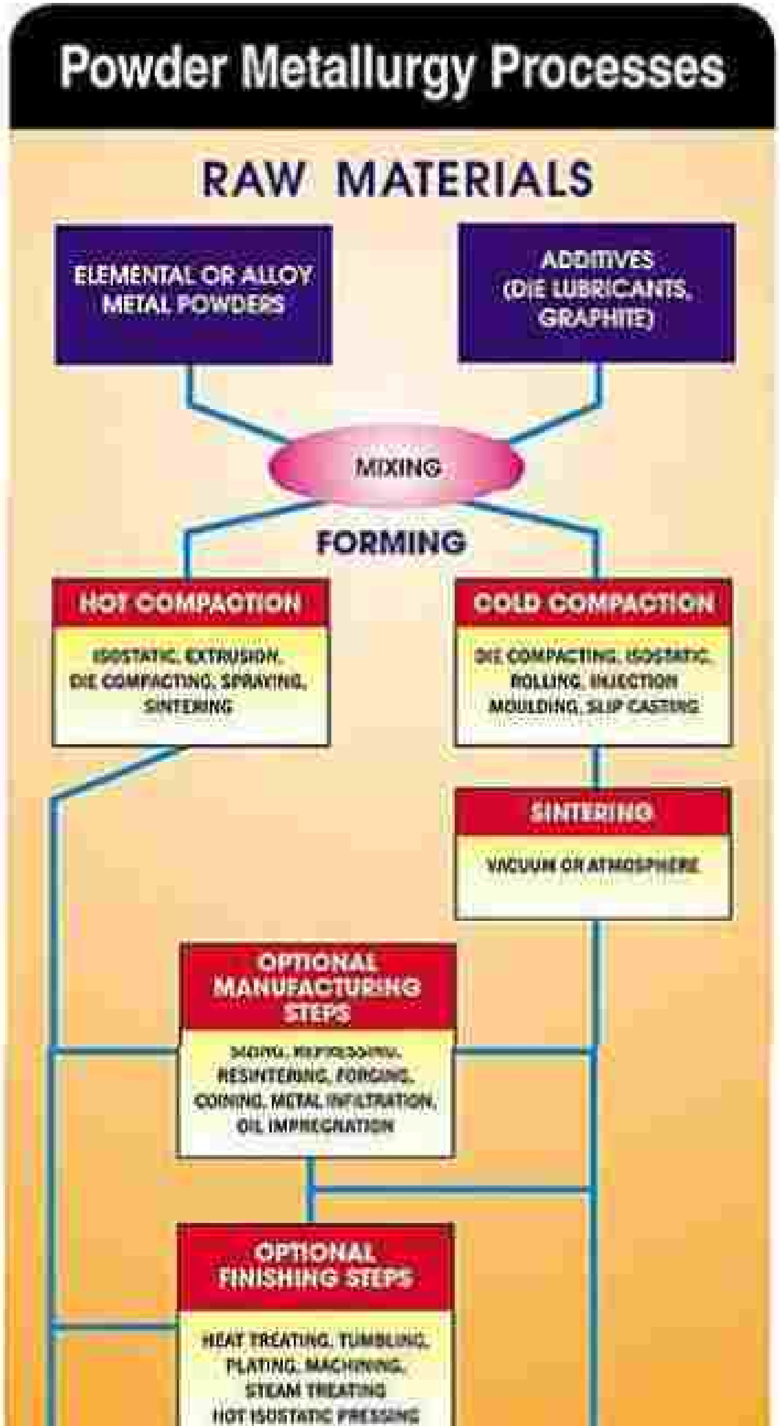
Metal Powder Industries Federation
105 College Road East • Princeton, New Jersey 08540-6692 U.S.A.
TEL: (609) 452-7700 • FAX: (609) 987-8523 • E-mail:

By producing parts with *a homogeneous structure* the PM process enables manufacturers to make products that are *more consistent* and *predictable in their behaviour* across a wide range of applications.

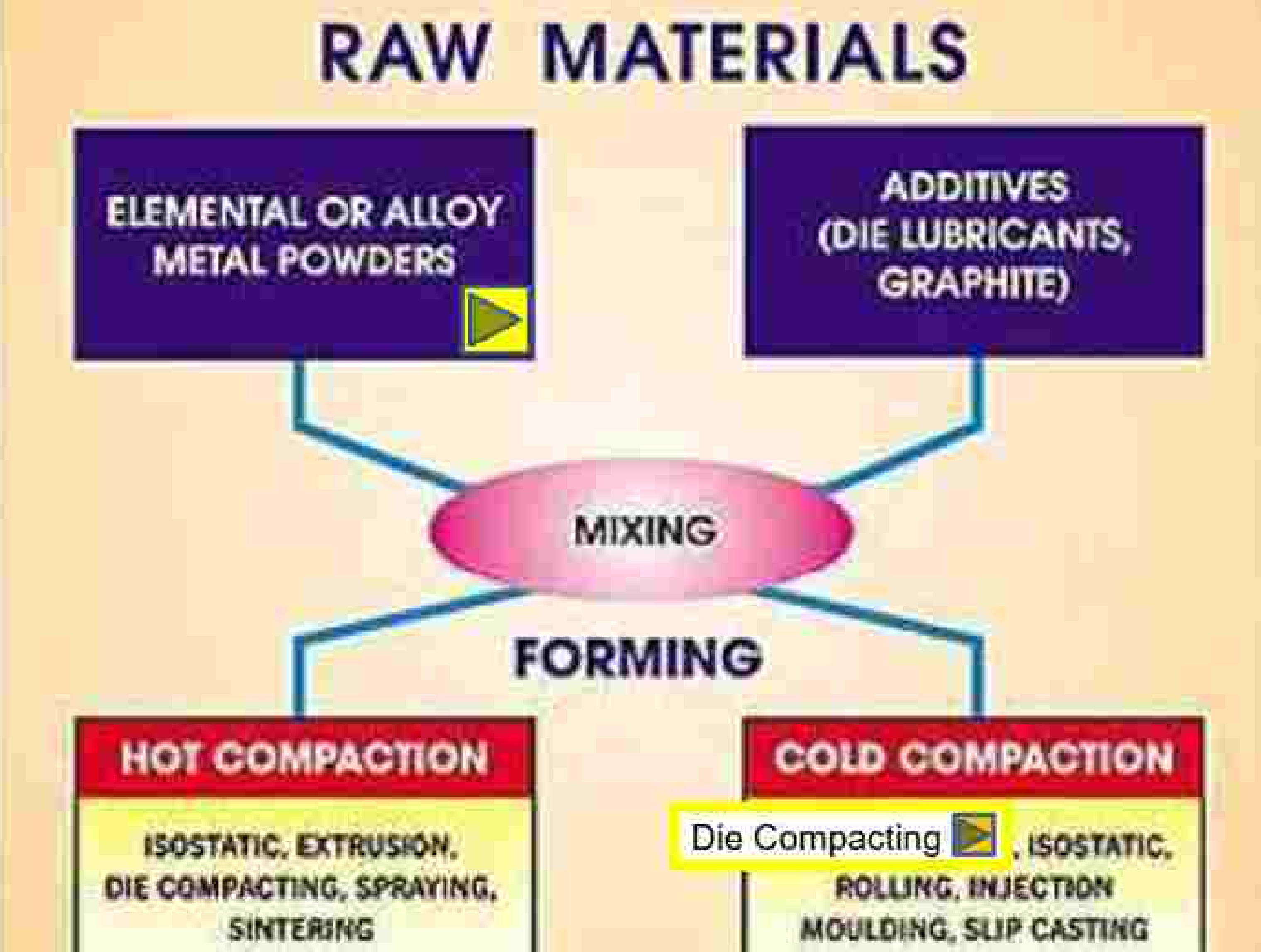
Advantages:

- Structural pieces with complex shapes
- Controlled Porosity
- Controlled performance
- Good performance in stress and absorbing of vibration
- Special properties such as hardness and wear resistance
- Great precision and good surface finish
- Large series of pieces with narrow tolerances

The high precision forming capability of PM generates components with near net shape, intricate features and good dimensional precision pieces are often finished without the need of machining.

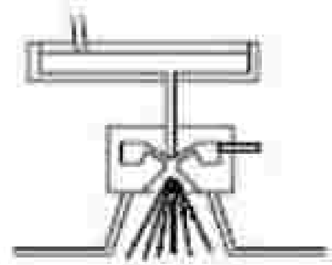

Powder Metallurgy Processes
RAW MATERIALS
ELEMENTAL OR ALLOY METAL POWDERS
ADDITIVES (DIE LUBRICANTS, GRAPHITE)
MIXING
FORMING
HOT COMPACTION
ISOSTATIC, EXTRUSION, DIE COMPACTING, SPRAYING, SINTERING
COLD COMPACTION
DIE COMPACTING, ISOSTATIC, ROLLING, INJECTION MOULDING, SLIP CASTING
SINTERING
VACUUM OR ATMOSPHERE
OPTIONAL MANUFACTURING STEPS
RESINTERING, FORGING, COINING, METAL INFILTRATION, OIL IMPREGNATION
OPTIONAL FINISHING STEPS
HEAT TREATING, TUMBLING, PLATING, MACHINING, STEAM TREATING
HOT ISOSTATIC PRESSING

Powder Metallurgy Processes

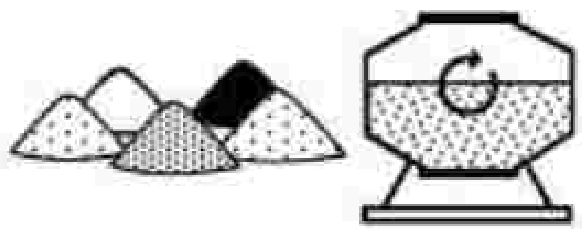


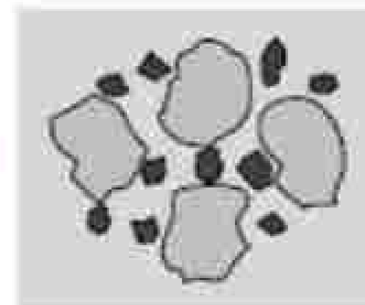
Alloying Methods of Iron Powders

Completely Alloyed Powder

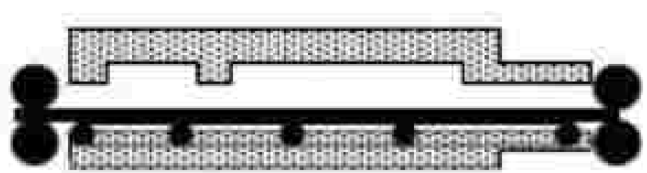


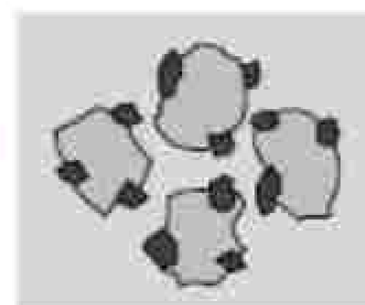
Mixed Alloyed Powder



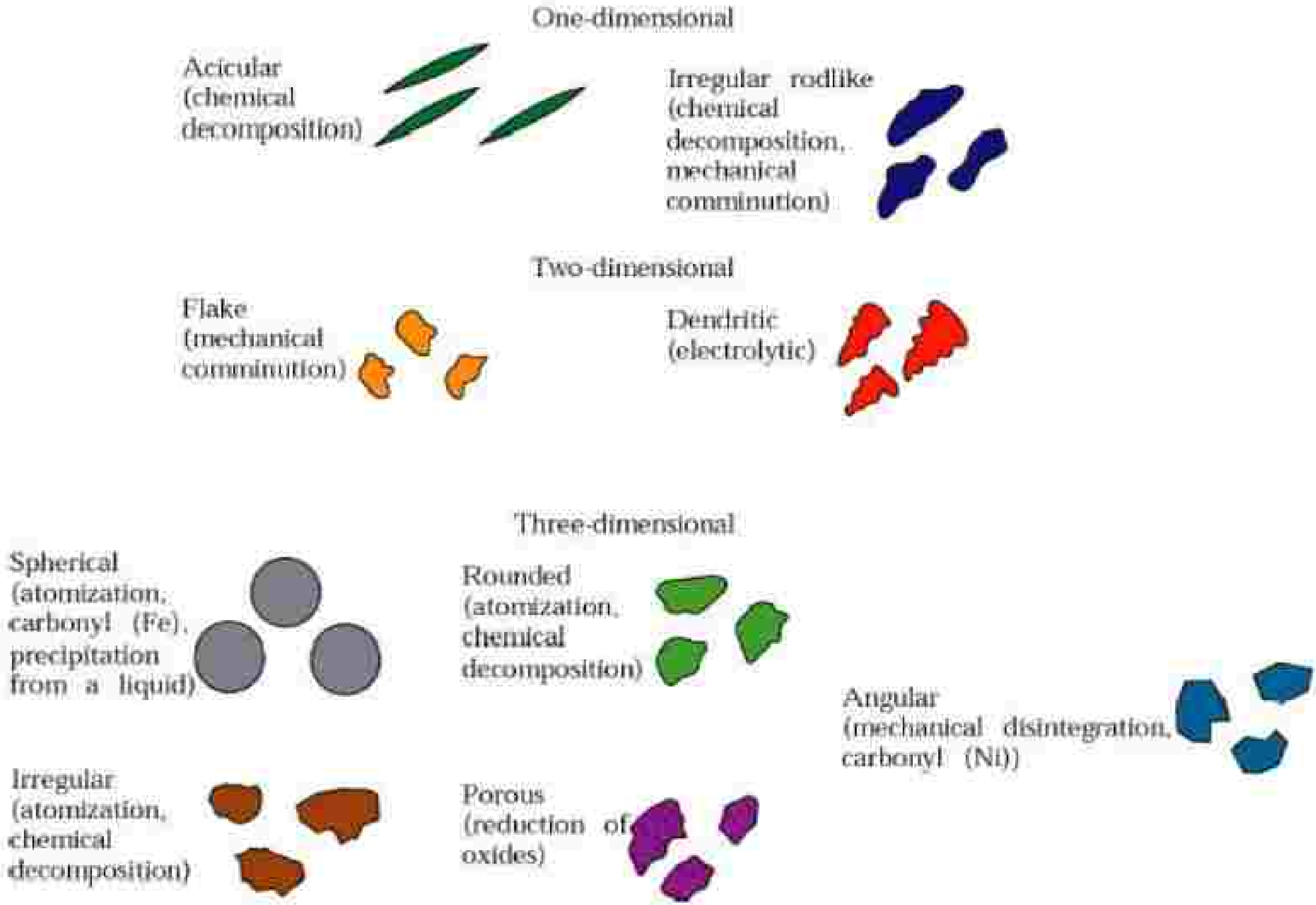


Partially Alloyed Powder

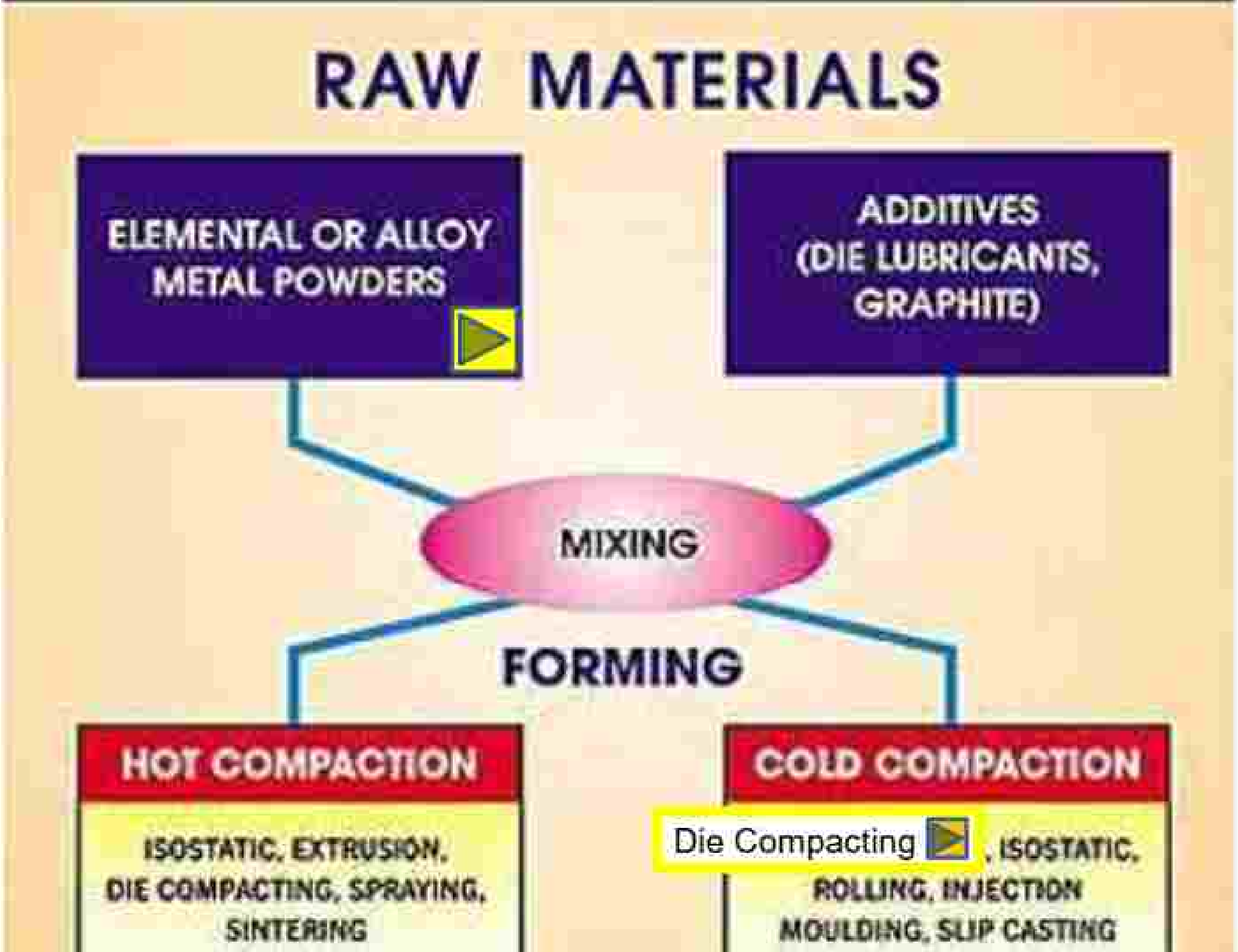




Particle Shapes in Metal Powders



Powder Metallurgy Processes

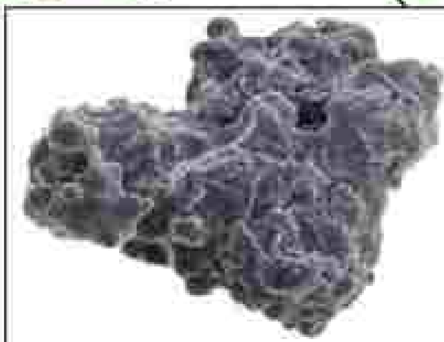


Material:

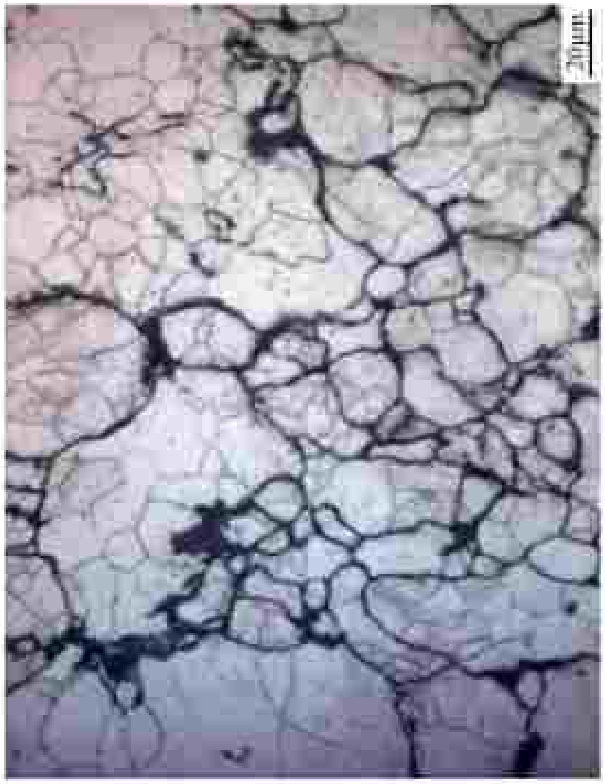
Fe-Cr-Mo-C (Fe - 1.5% Cr – 0.2% Mo)+ 0.6% C

Properties of **Fe-Cr-Mo** powder	
Apparent density	2.85 g/cm^3
Flow	26 sec/50g
Particle size	45-150 μm
Chemical analysis, %	
C	<0.01
Chromium	1.50
Molybdenum	0.20

Fe-Mo-C (Fe - 1.5% Mo)+ 0.6% C



Properties of **Fe-Mo** powder	
Apparent density	3.1 g/cm^3
Flow	25 sec/50g
Particle size	45-150 μm
Chemical analysis, %	
C	<0.01
Molybdenum	1.50



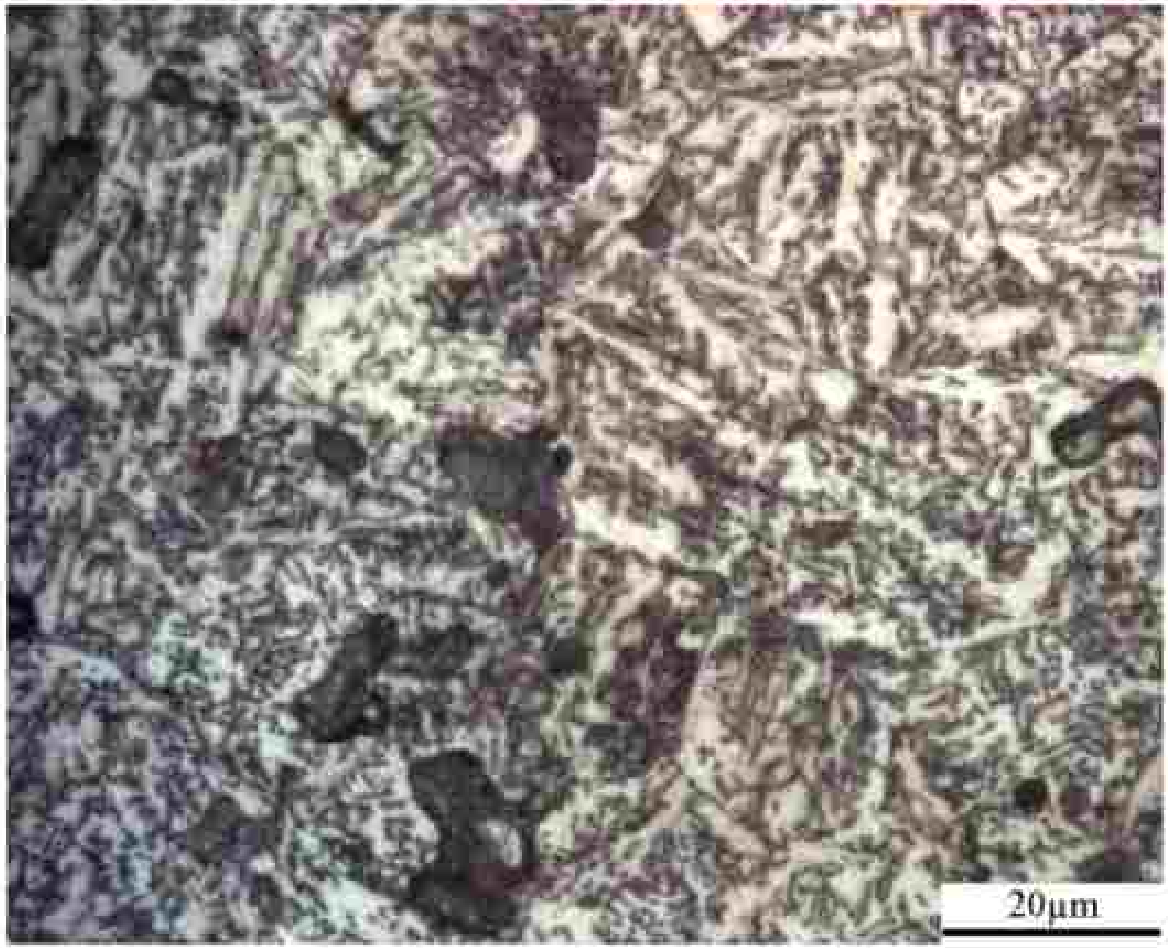
At 700 °C

At 800 °C

At 900 °C

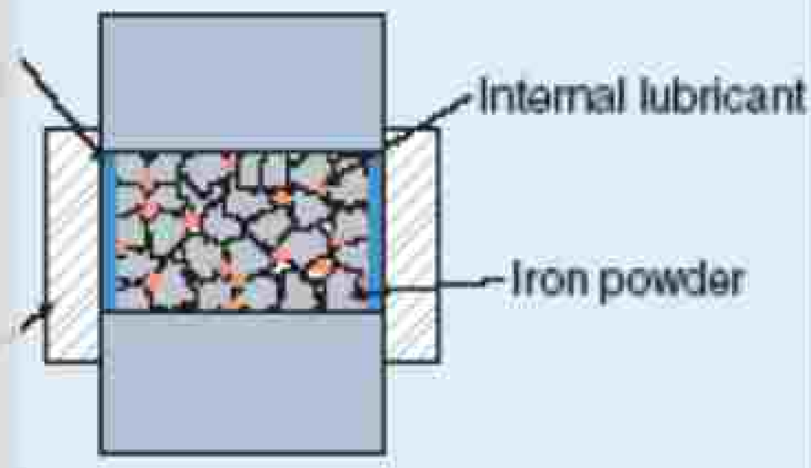
Microstructure of **Fe-Mo-C**,
compacted at **600 MPa** and
1[st] sintered at the indicated temperature for 30 min, and
repressed at **600 MPa**. (As repressed)

Sintered Fe-Cr-Mo-C



1st sintering Temperature=800°C

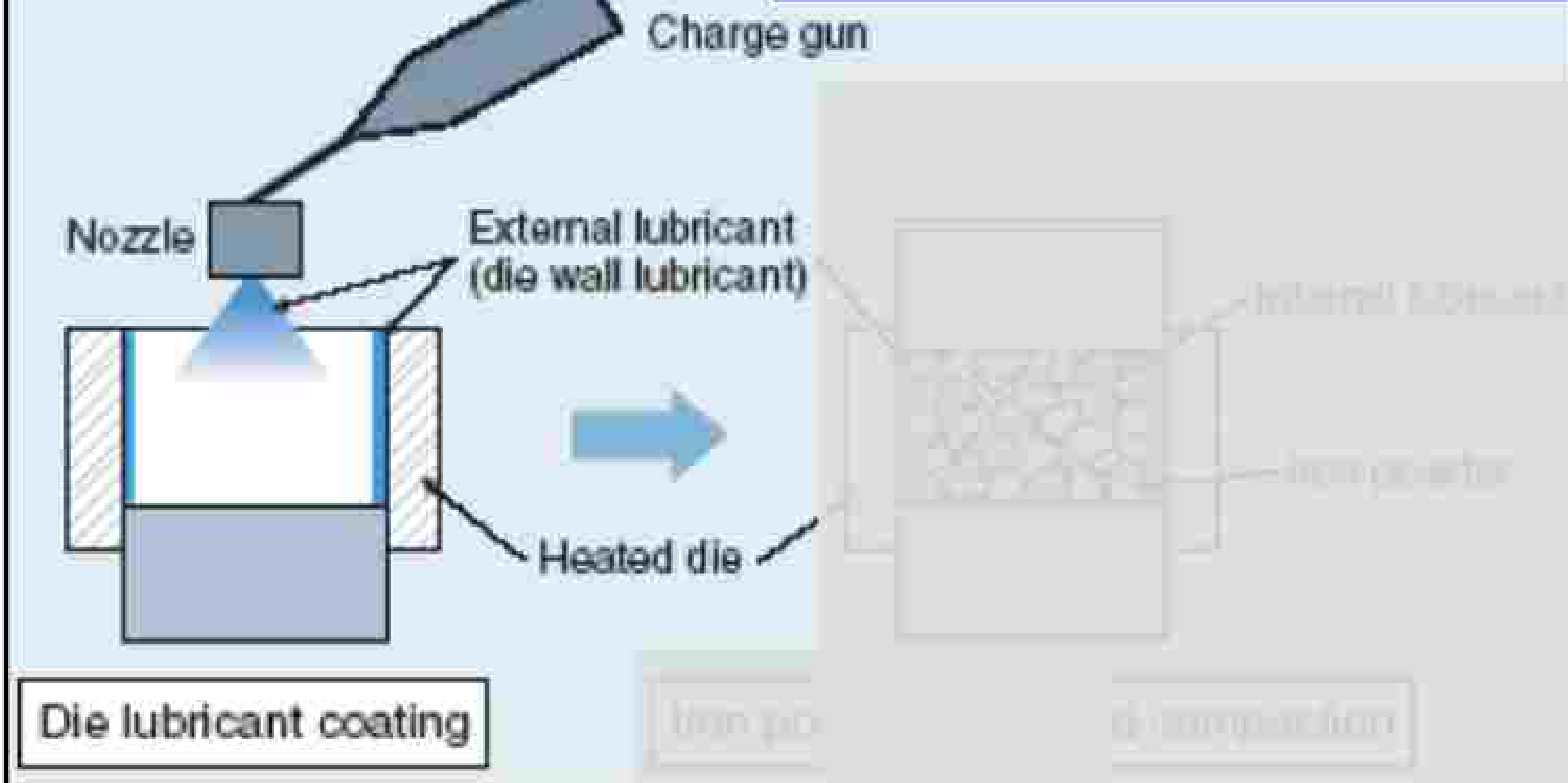
There are two lubrication techniques.



One method is to blend a dry lubricant with the powdered metal.

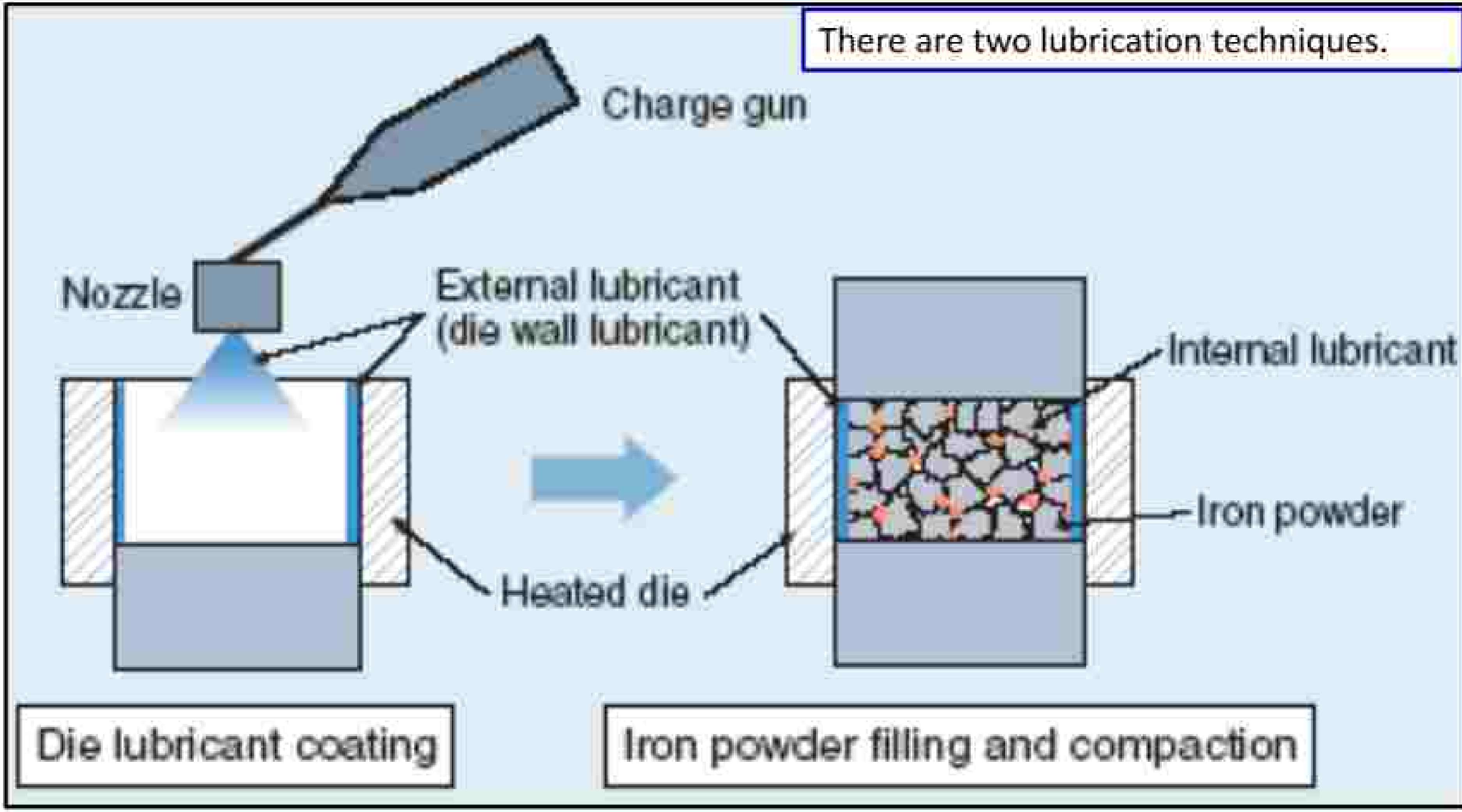
With the powder lubrication method, the level of lubricant addition may range from 0.5 to 1.5%.

There are two lubrication techniques.



The other method, commonly referred to as die wall lubrication, is to lubricate the die walls and punches of the compacting tooling prior to introducing the powder metal into the die cavity.

With die wall lubrication, the solid lubricant (for example, zinc stearate, 100 g) is mixed with a volatile organic liquid (for example, methylchloroform, 1 L) and is either painted or sprayed on the tooling. The organic liquid evaporates, leaving a thin film of dry lubricant on the working surfaces of the die cavity and punches.


There are two lubrication techniques.
Charge gun
Nozzle
External lubricant
(die wall lubricant)
Internal lubricant
Iron powder
Heated die
Die lubricant coating
Iron powder filling and compaction

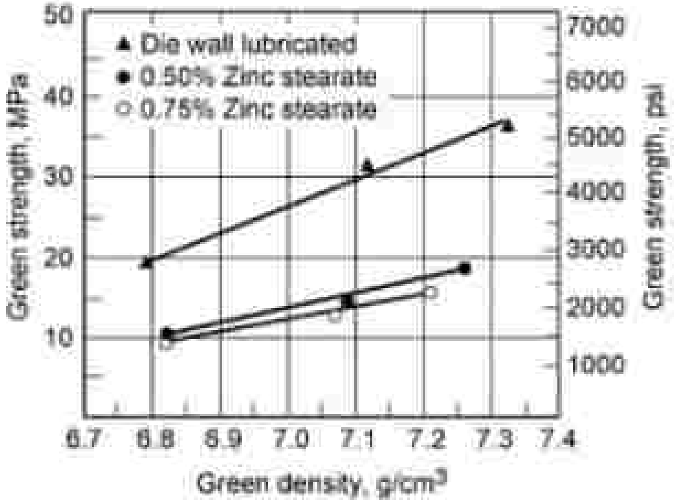


Fig. 9 Effect of lubrication method on green strength. Source: Ref 1

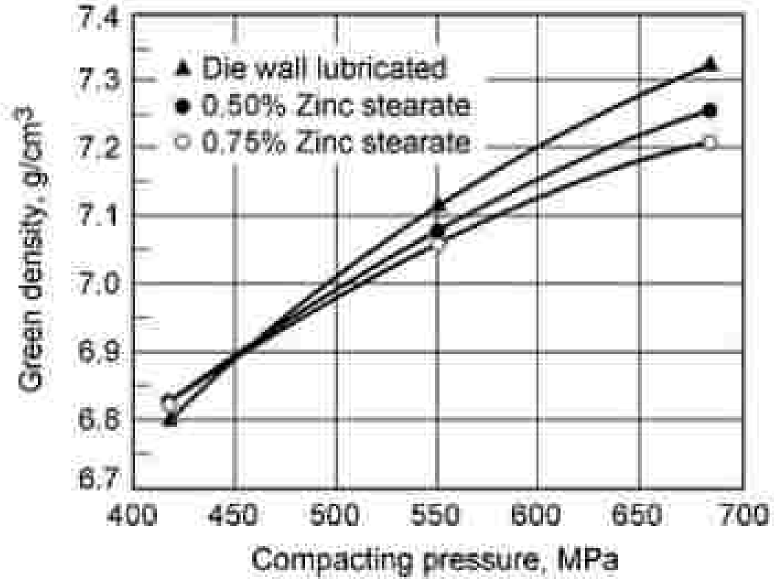


Fig. 10 Effect of lubrication on green density. Source: Ref 1

Lubricants. The effect of lubricants on compressibility depends on the lubricant and the compaction pressures. Some lubricants perform better than others, but generally lubricants cause a reduction in green strength (Fig. 9).

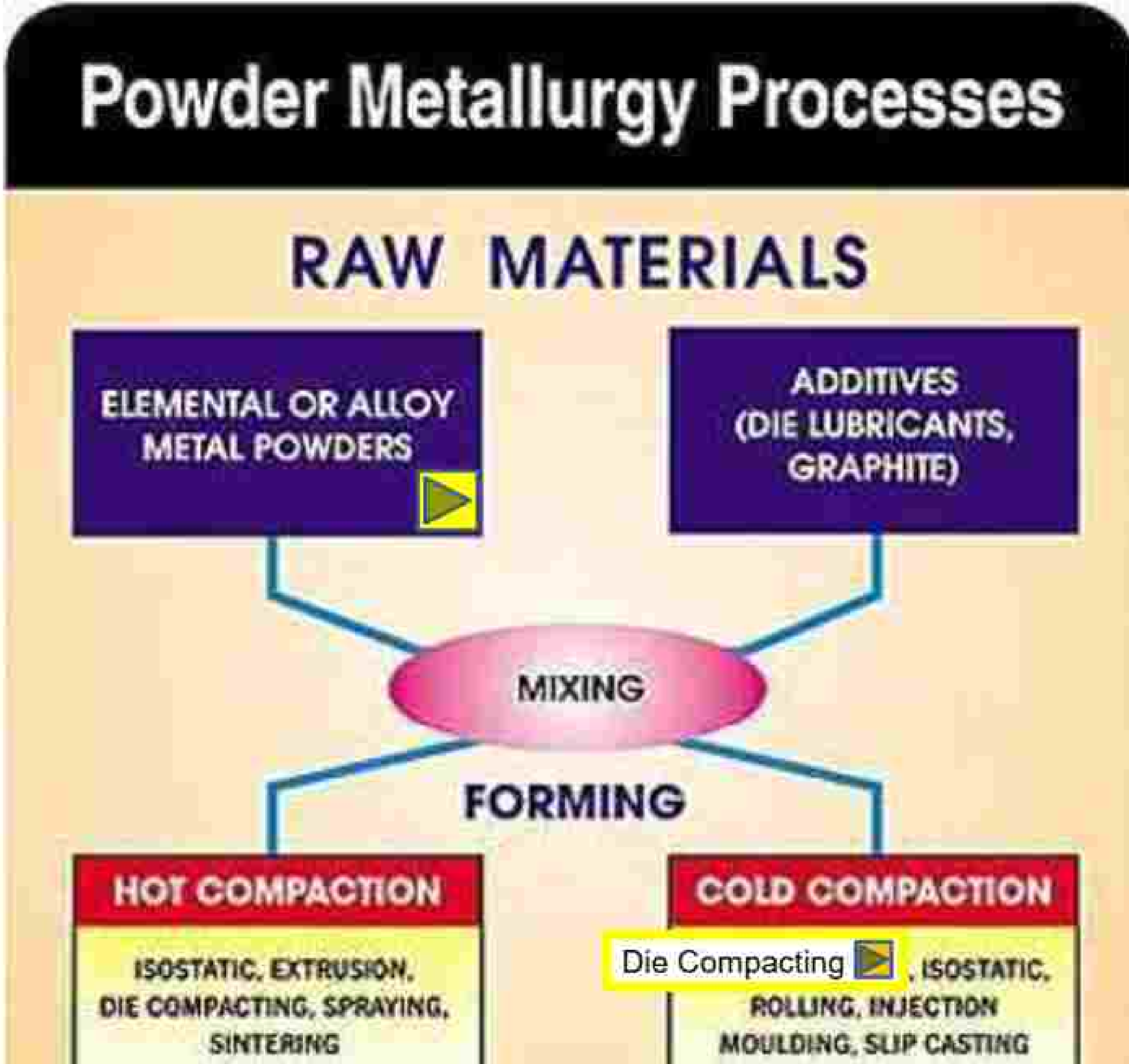
The reduction in compressibility from lubricants is more pronounced at higher compaction pressures (Fig. 10). At higher compaction pressures, lubricants reduce the green density because it occupies the available porosity.

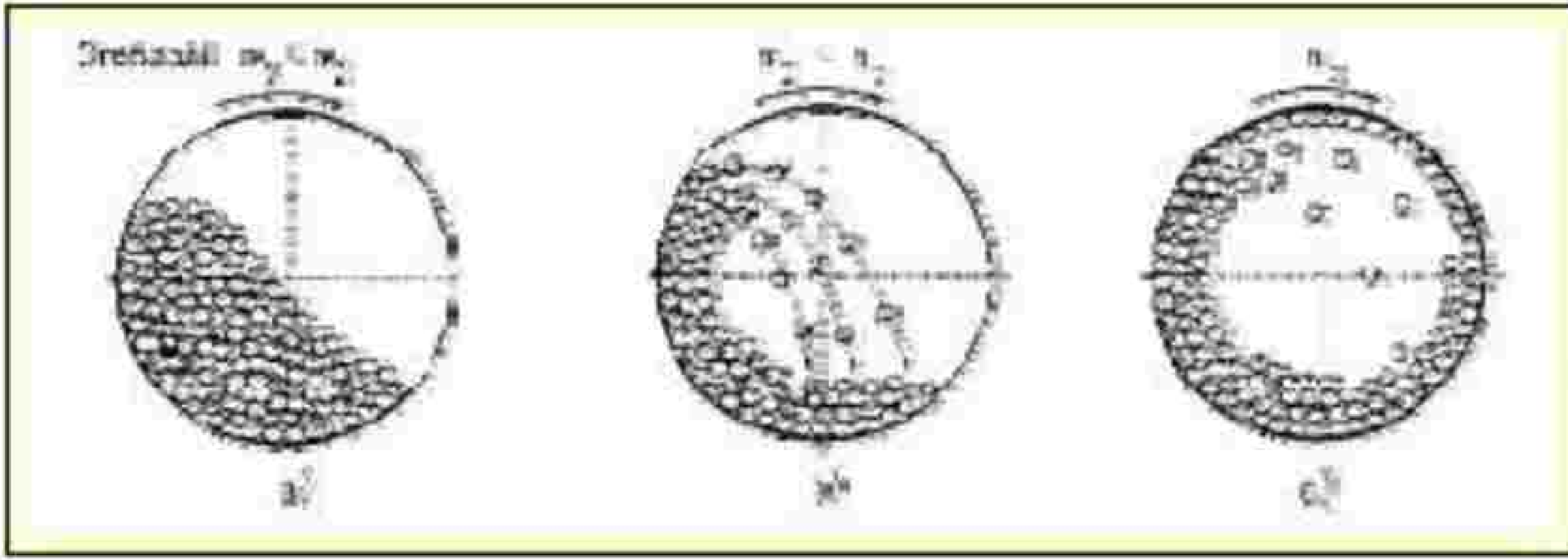
There are two lubrication techniques. One method is to blend a dry lubricant with the powdered metal.

With the powder lubrication method, the level of lubricant addition may range from 0.5 to 1.5%.

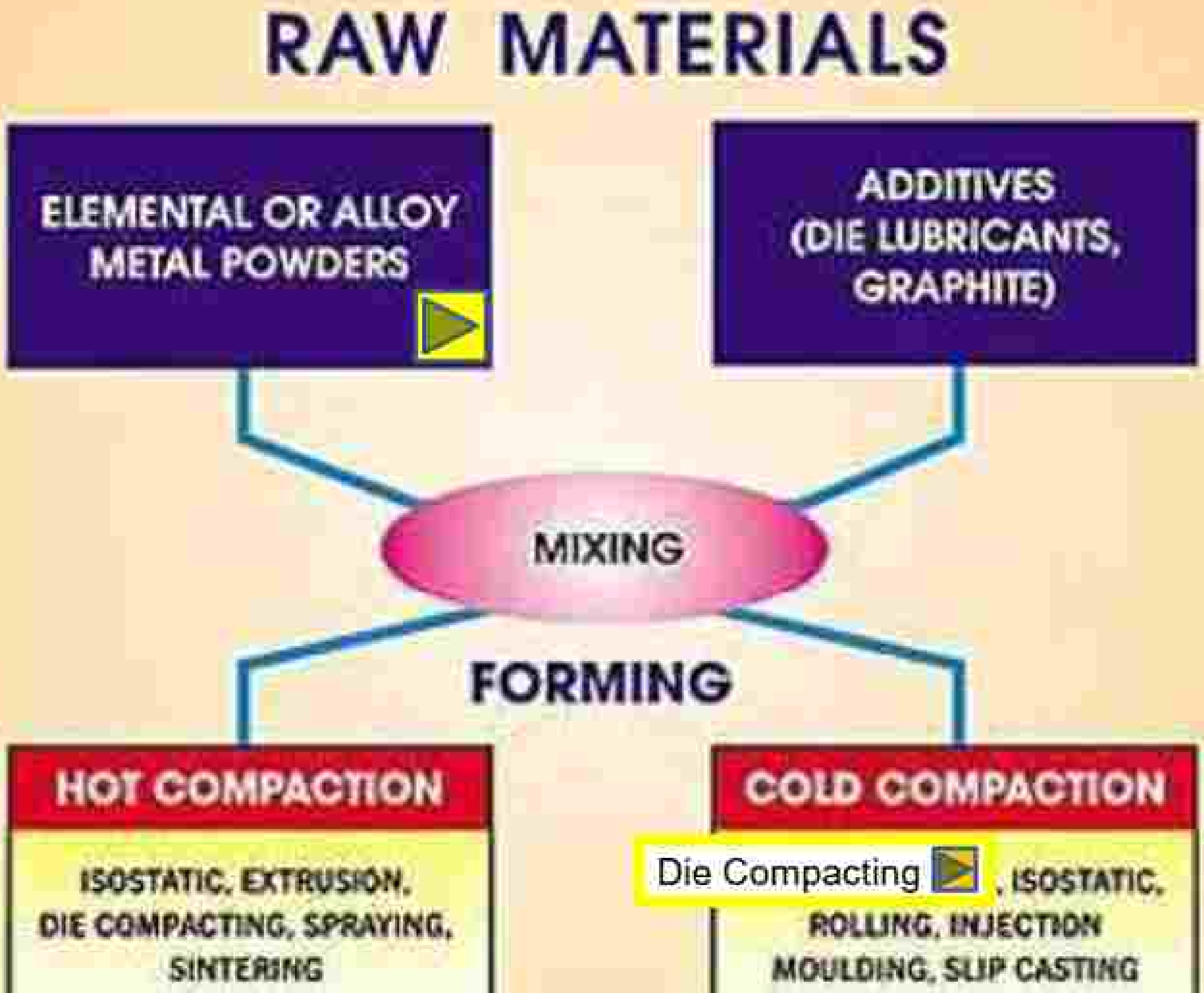
The other method, commonly referred to as die wall lubrication, is to lubricate the die walls and punches of the compacting tooling prior to introducing the powder metal into the die cavity.

With die wall lubrication, the solid lubricant (for example, zinc stearate, 100 g) is mixed with a volatile organic liquid (for example, methylchloroform, 1 L) and is either painted or sprayed on the tooling. The organic liquid evaporates, leaving a thin film of dry lubricant on the working surfaces of the die cavity and punches.

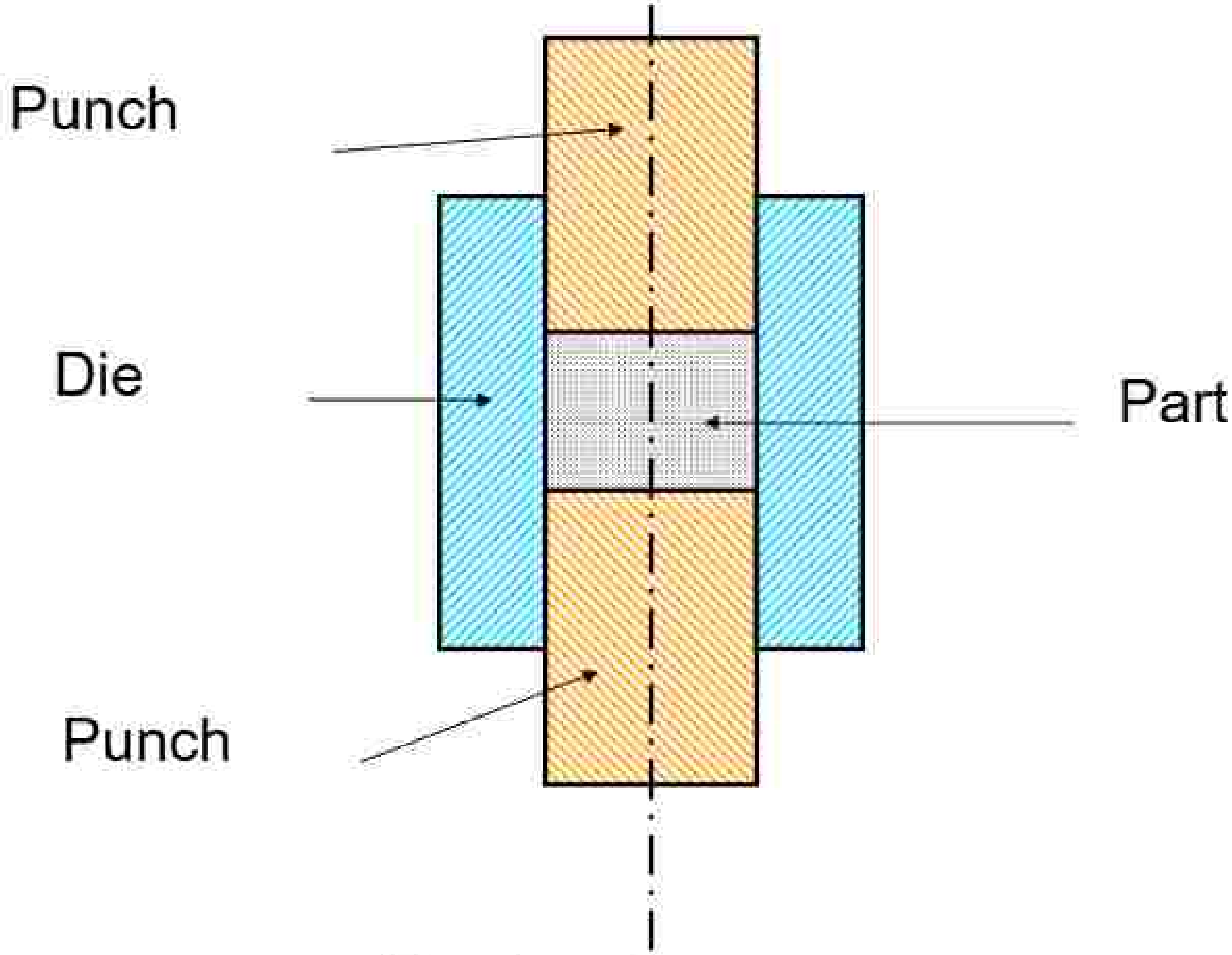

Powder Metallurgy Processes
RAW MATERIALS
ELEMENTAL OR ALLOY METAL POWDERS
ADDITIVES (DIE LUBRICANTS, GRAPHITE)
MIXING
FORMING
HOT COMPACTION
ISOSTATIC, EXTRUSION, DIE COMPACTING, SPRAYING, SINTERING
COLD COMPACTION
Die Compacting
, ISOSTATIC, ROLLING, INJECTION MOULDING, SLIP CASTING



Powder Metallurgy Processes



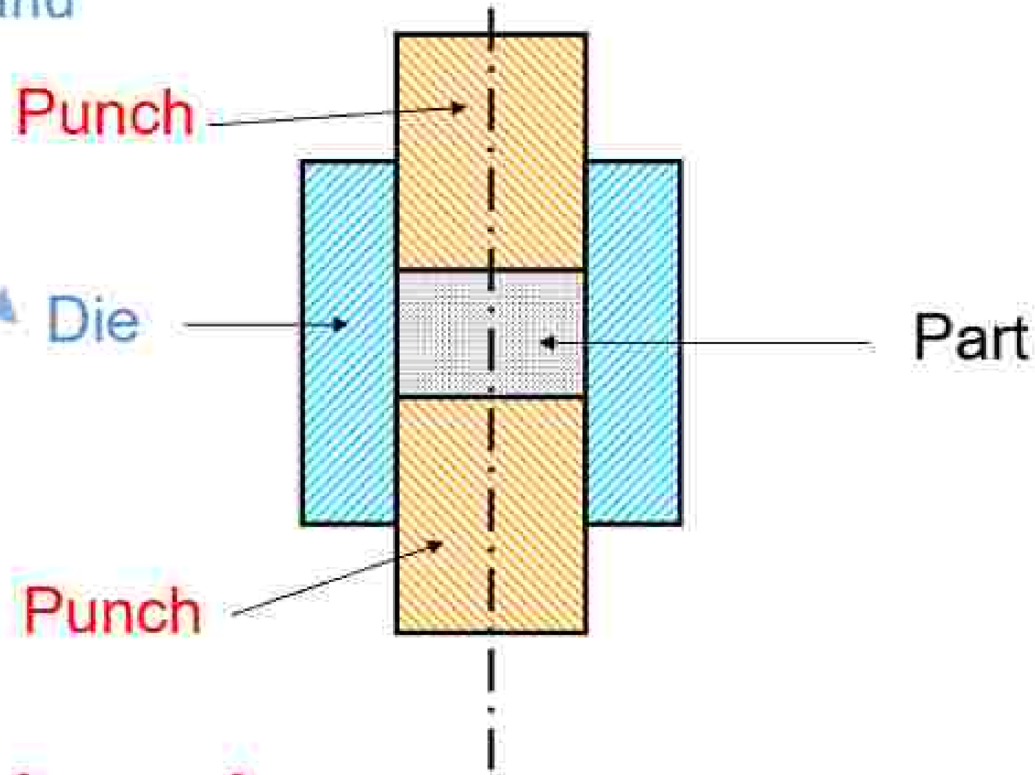
Powder Pressing



Dual action press

Tooling used to make these specimens consists of

- **a die**, preferably of cemented carbide, or alternatively of tool steel, and

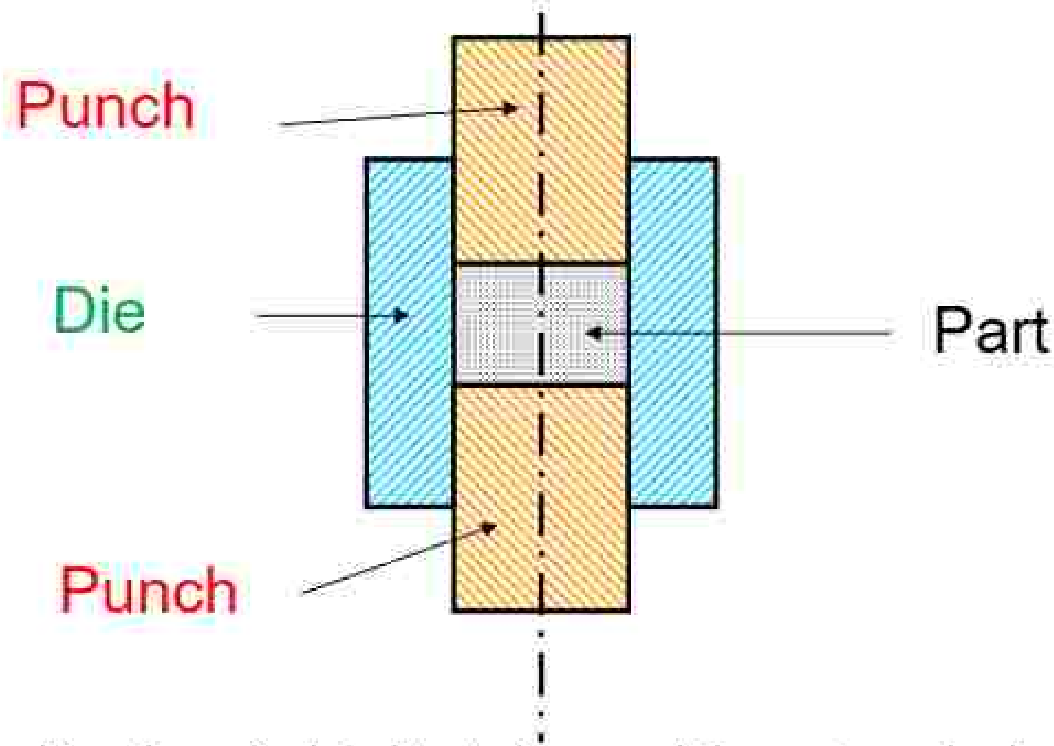


- **two steel punches** for producing either cylindrical or rectangular compacts.

Exact tool dimensions required for making the cylindrical test piece and the rectangular bar are described in MPIF 45 and ISO 3927.

Tooling used to make these specimens consists of

- **a die**, preferably of cemented carbide, or alternatively of tool steel, and
- **two steel punches** for producing either cylindrical or rectangular compacts.



Exact tool dimensions required for making the cylindrical test piece and the rectangular bar are described in MPIF 45 and ISO 3927.

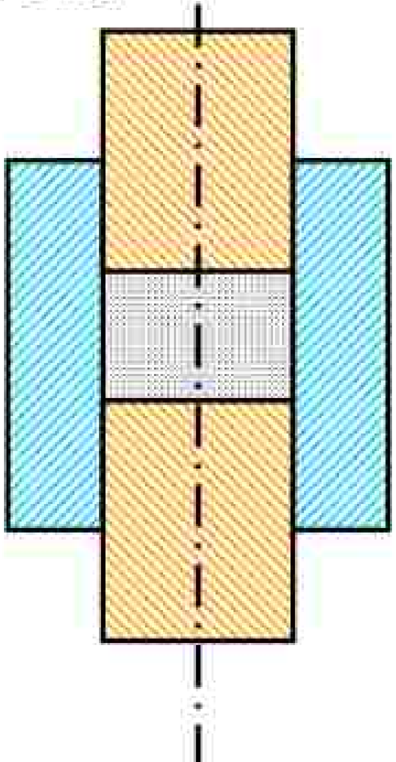
Compacting

- Loose powder is compacted and densified into a shape, known as **green compact**

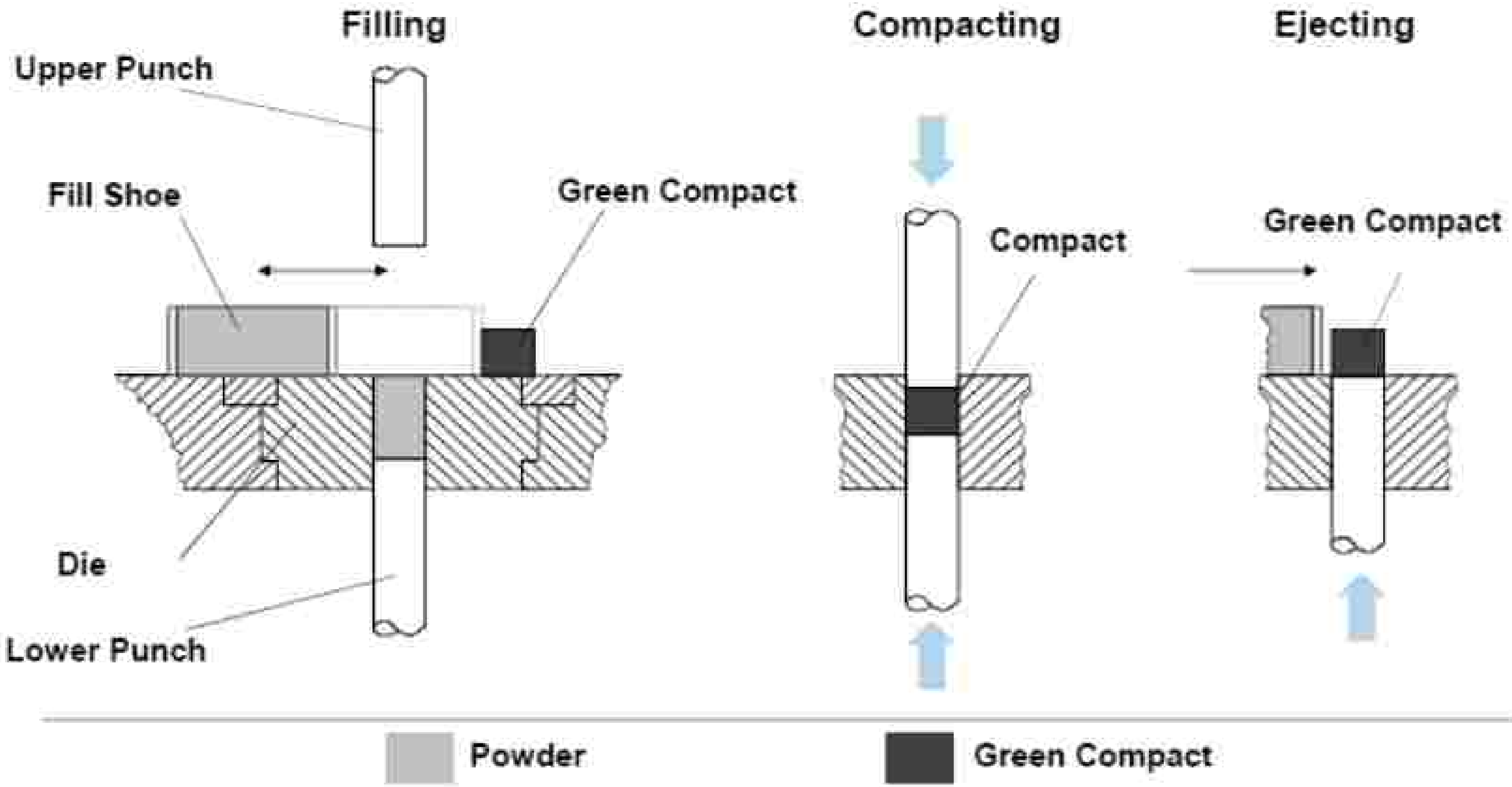
- Most compacting is done with mechanical presses and rigid tools

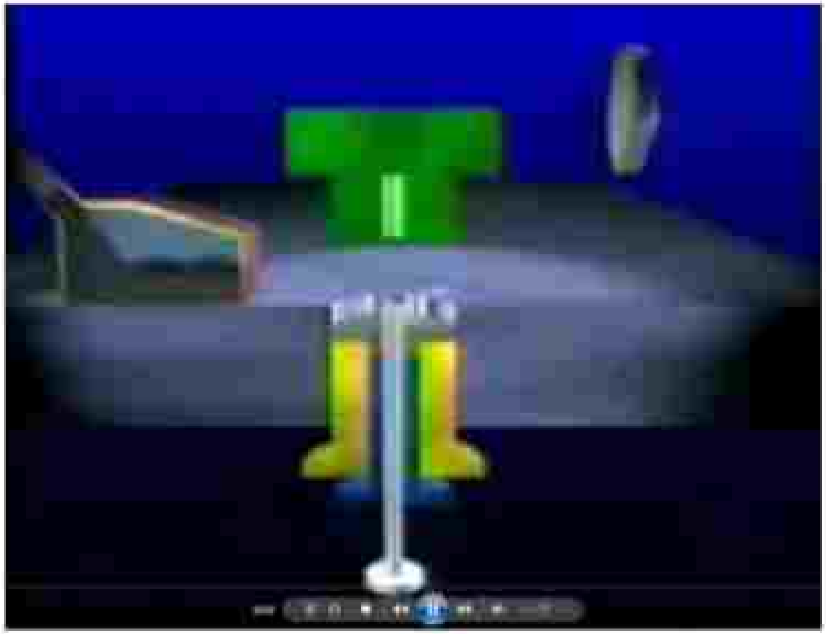
TABLE 18-1 Typical Compacting Pressures for Various Applications

Application	Compaction Pressures tons/in.^{2}	Compaction Pressures Mpa
Porous metals and filters	3–5	40–70
Refractory metals and carbides	5–15	70–200
Porous bearings	10–25	146–350
Machine parts (medium-density iron & steel)	20–50	275–690
High-density copper and aluminum parts	18–20	250–275
High-density iron and steel parts	50–120	690–1650



The Compaction Cycle





Compressibility Testing

Standard test methods for compressibility have been issued as:

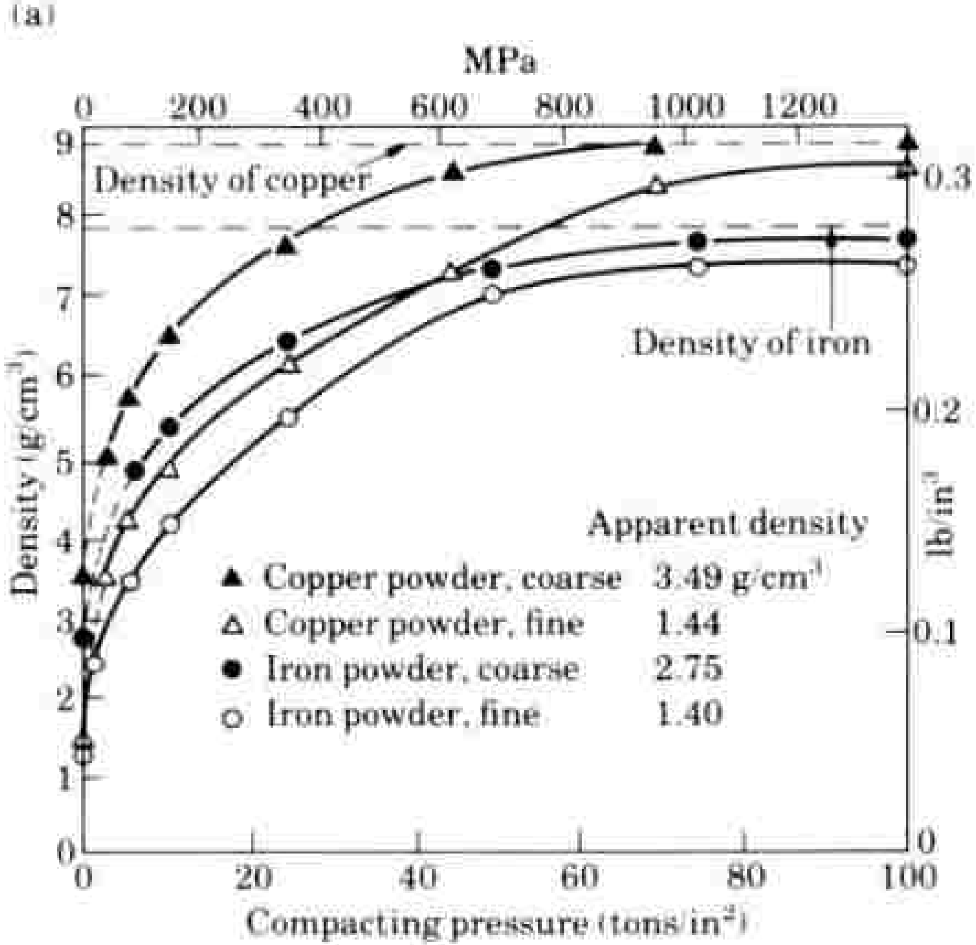
- ASTM B331, "Compressibility of Metal Powder in Uniaxial Compaction," by the American Society for Testing and Materials
- MPIF 45, "Determination of Compressibility of Metal Powders," by the Metal Powder Industries Federation
- ISO 3927, "Metallic Powders Excluding Powders for Hardmetals--Determination of Compactibility

Typically, a cylindrical or rectangular test piece is made
by pressing powder in a die,
with pressure applied simultaneously from top and bottom.

The pressure required to achieve a specified density is a measure of **compressibility**.

Compressibility ***can also be specified as***
the density achievable at a given pressure.

By plotting **the density** obtained by a series of increasing levels of **pressure** against these pressures, a compressibility curve is developed.



Compaction of Powder Metals

Two shapes of test pieces have been standardized.

- One is a **cylinder** having
  - a diameter of 25 mm (1 in.) and
  - a height of 12.7 to 25 mm (0.5 to 1 in.).

- The other is a **rectangular** bar
  - 12.7 mm (0.5 in.) wide
  - 31.8 mm (1.25 in.) long and
  - 5 to 7 mm (0.2 to 0.3 in.) high.

COMPRESSION RATIO

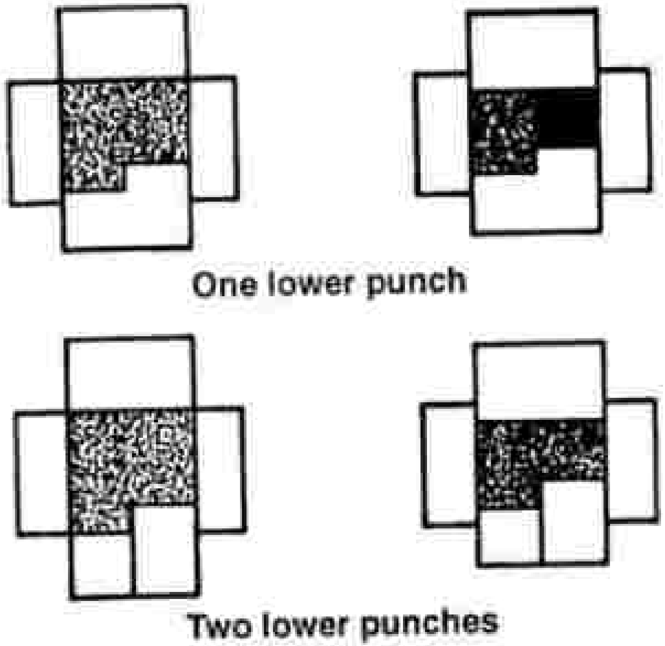
The compression ratio applies to uniaxial die pressing. It is defined as the ratio of the height of loose powder to the height of the compact. For a constant cross-section compact, the compression ratio C_R expresses the volume change or density change with a standardized compaction pressure, say 400 MPa, and can be calculated from the density ratio, height ratio, or volume ratio:

$$C_R = \frac{H}{H_O} = \frac{V_L}{V_C} = \frac{\rho_G}{\rho_A}$$

C_R = compression ratio, dimensionless
H = compacted powder height, m (convenient units: mm)
H_O = loose-powder fill height, m (convenient units: mm)
V_C = compacted-powder volume, m^3 (convenient units: mm^3)
V_L = loose-powder fill volume, m^3 (convenient units: mm^3)
ρ_A = loose-powder apparent density, kg/m^3 (convenient units: g/cm^3)
ρ_G = pressed green density, kg/m^3 (convenient units: g/cm^3).

Figure 18-3 (Left) Typical press for the compacting of metal powders. A removable die set (right) allows the machine to be producing parts with one die set while another is being fitted to produce a second product. (*Courtesy of Alfa Laval, Inc., Warminster, PA.*)

Compaction of Powders



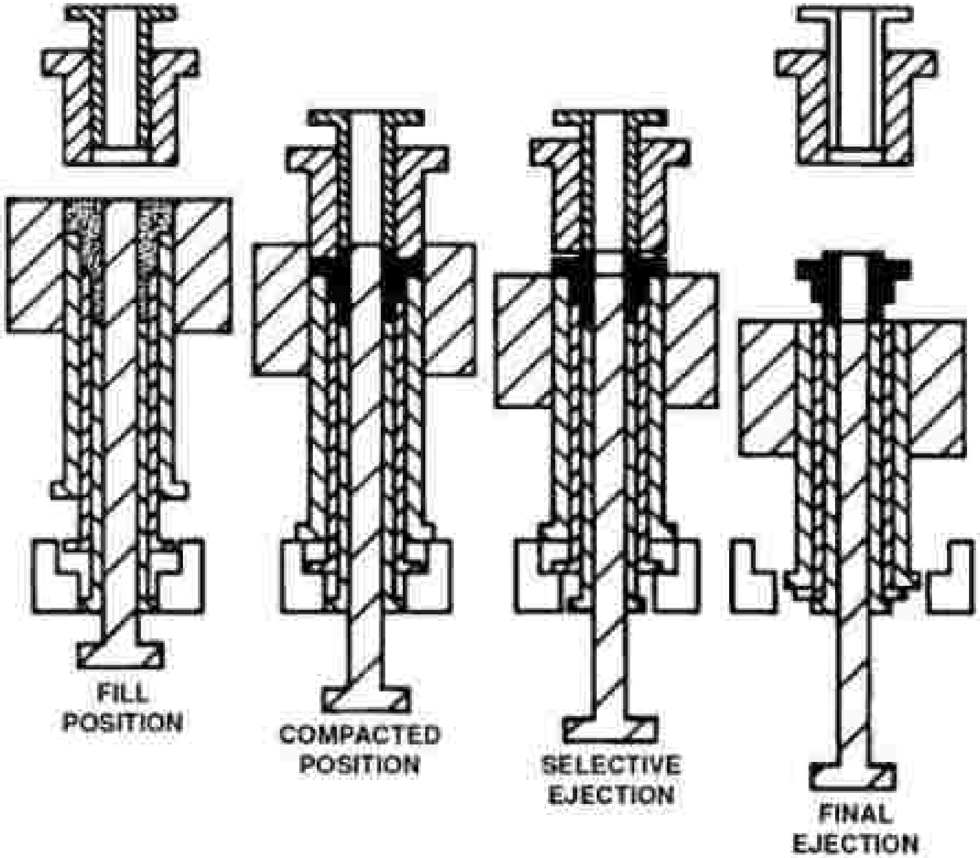
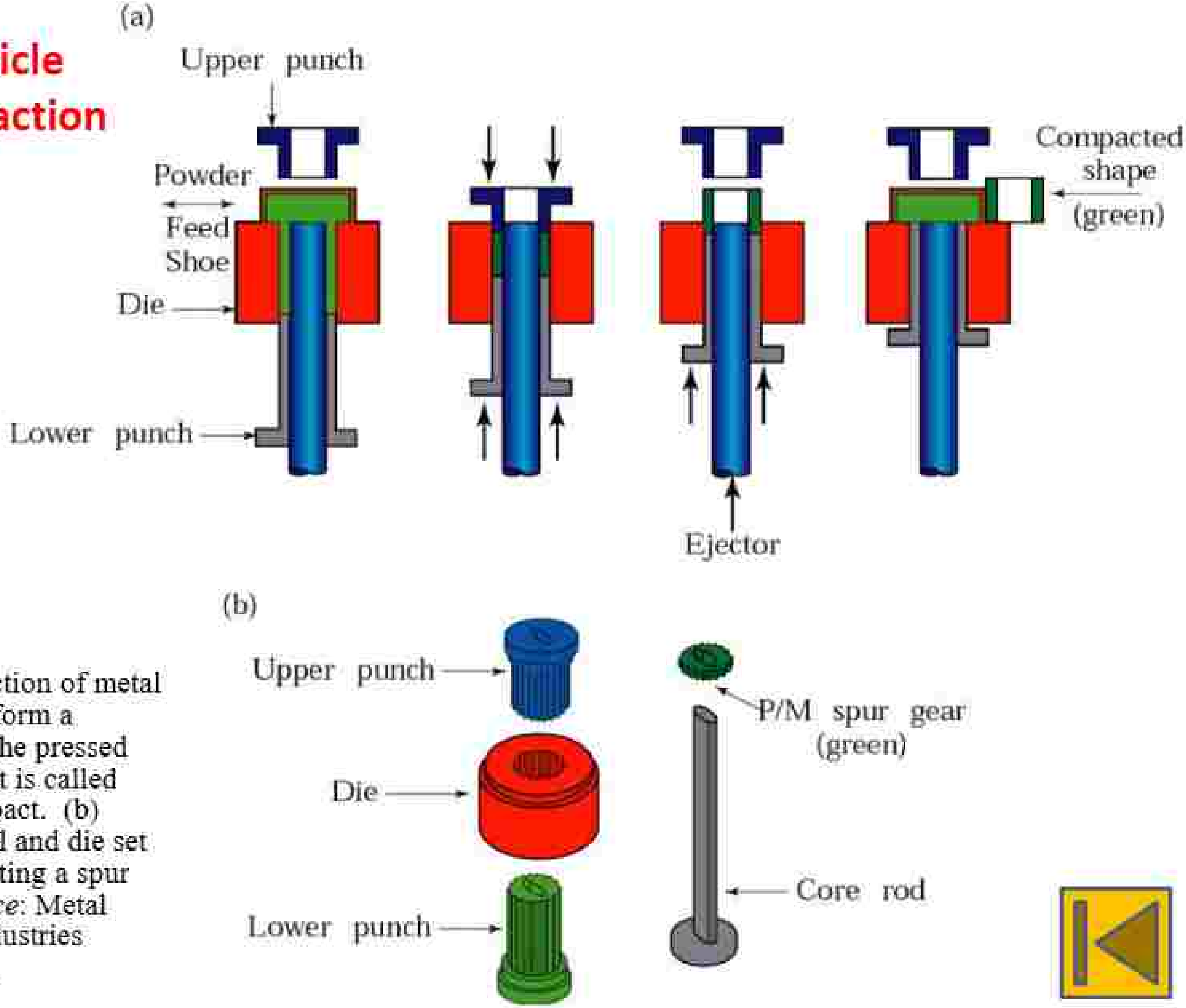


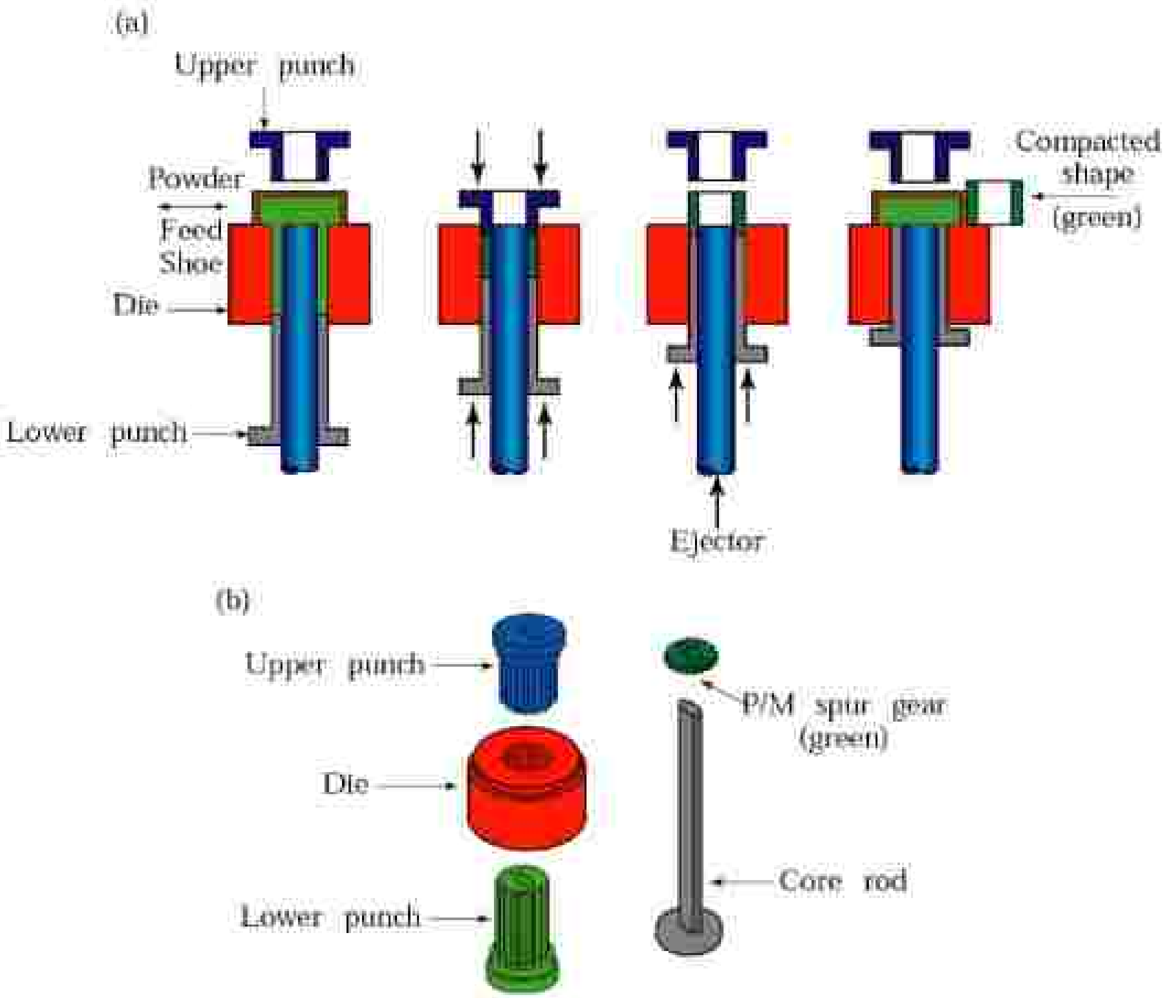
FIG. 11.13 Typical compaction tool elements for a multilevel part. (From Ref. 9.)

Particle Compaction



(a) Compaction of metal powder to form a bushing. The pressed powder part is called green compact. (b) Typical tool and die set for compacting a spur gear. *Source*: Metal Powder Industries Federation.

Compaction



(a) Compaction of metal powder to form a bushing. The pressed powder part is called green compact.
(b) Typical tool and die set for compacting a spur gear.

$$Density = (\text{Theoretical density of metal}) \times \left(1 - \frac{\%\text{porosity}}{100}\right)$$

$$Conductivity = (\text{Theoretical conductivity of metal}) \times \left(1 - 2\frac{\%\text{porosity}}{100}\right)$$

COMPACTION-INDUCED NECK SIZE

HW :تکلیف

Pressure will rearrange and deform contacting particles, inducing an incipient neck between them. The size of that initial neck depends on both the material properties and applied pressure. If no pressure is applied, there is still a small degree of elastic deformation, leading to a small insipient neck. The compaction-induced deformation at the particle contacts produces a circular contact that expands in size with higher pressures. At high relative pressures compared to the material strength, assuming plasticity, the deformed particles will consist entirely of prismatic faces. Prior to formation of prismatic grains, the size of the contact faces can be approximated by a circle of diameter X. The fractional green density f_G and contact size are related as follows:

$$X = D\left[1 - \left(\frac{f_G}{f_A}\right)^{2/3}\right]^{1/2}$$

where D is the particle diameter, and f_A is the fractional apparent density corresponding to $X = 0$. In uniaxial die compaction, the applied pressure decays with depth below the punch. Accordingly, the compaction-induced initial neck size will vary with position in the green body.

D = particle size, m (convenient units: μm)
X = diameter of contact between pressed powders, m (convenient units: μm)
f_A = apparent density, dimensionless fraction [0, 1]
f_G = green density, dimensionless fraction [0, 1].

GREEN DENSITY DEPENDENCE ON COMPACTION PRESSURE (Jones 1960)

In powder compaction the average green density depends on the average compaction stress. Since wall friction decreases the average stress, thicker compacts in the pressing direction will naturally have lower densities. On close scrutiny, there are density gradients within the compact. If it is complicated in shape, especially if there are multiple thicknesses, then the green density can be highly variable within the body. As an approximation, the average fractional green density f_G will depend on the compaction pressure P approximately as follows:

$$\frac{df_G}{dP} = -\Theta\varepsilon = -\Theta(1 - f_G)$$

where ε is the fractional porosity ($\varepsilon = 1 - f_G$), and Θ is a constant that varies with the powder. Rearranging and integrating gives,

$$\ln\left(\frac{1 - f_G}{1 - f_D}\right) = -\Theta P$$

where f_D is the fractional density at the onset of deformation, which is often near the tap density. This equation does not include particle rearrangement, so the addition of a term to include early-stage effects gives,

$$\ln\left(\frac{1 - f_G}{1 - f_D}\right) = B - \Theta P$$

where B is added to account for particle rearrangement. Modified expressions build from this with terms for deformation and particle hardening. Accordingly, a generic model linking green density to compaction pressure results,

$$f_G = 1 - (1 - f_D)\exp(B - \Theta P)$$

where f_D can be approximated by the apparent or tap density. In some cases, a simplified version can be used to link fractional green density f_G to compaction pressure P,

$$f_G = f_A - A\exp(-KP)$$

where f_A is the apparent density of the powder, and A and K are constants that change with each powder.

A = material constant, dimensionless
B = rearrangement constant, dimensionless
f_A = fractional apparent density, dimensionless
K = constant, 1/Pa
P = compaction pressure, Pa (convenient units: MPa)
f_D = fractional density at the onset of deformation, dimensionless
f_G = fractional green density, dimensionless
Θ = powder-dependent constant, 1/Pa
$\varepsilon = 1 - f_G$ = fractional porosity, dimensionless.

GREEN DENSITY DEPENDENCE ON PUNCH TRAVEL

The green density ρ_G in compaction depends on the apparent powder density ρ_A, initial powder fill height H_0, and final compacted height H as follows:

$$\rho_G = \rho_A \frac{H_0}{H}$$

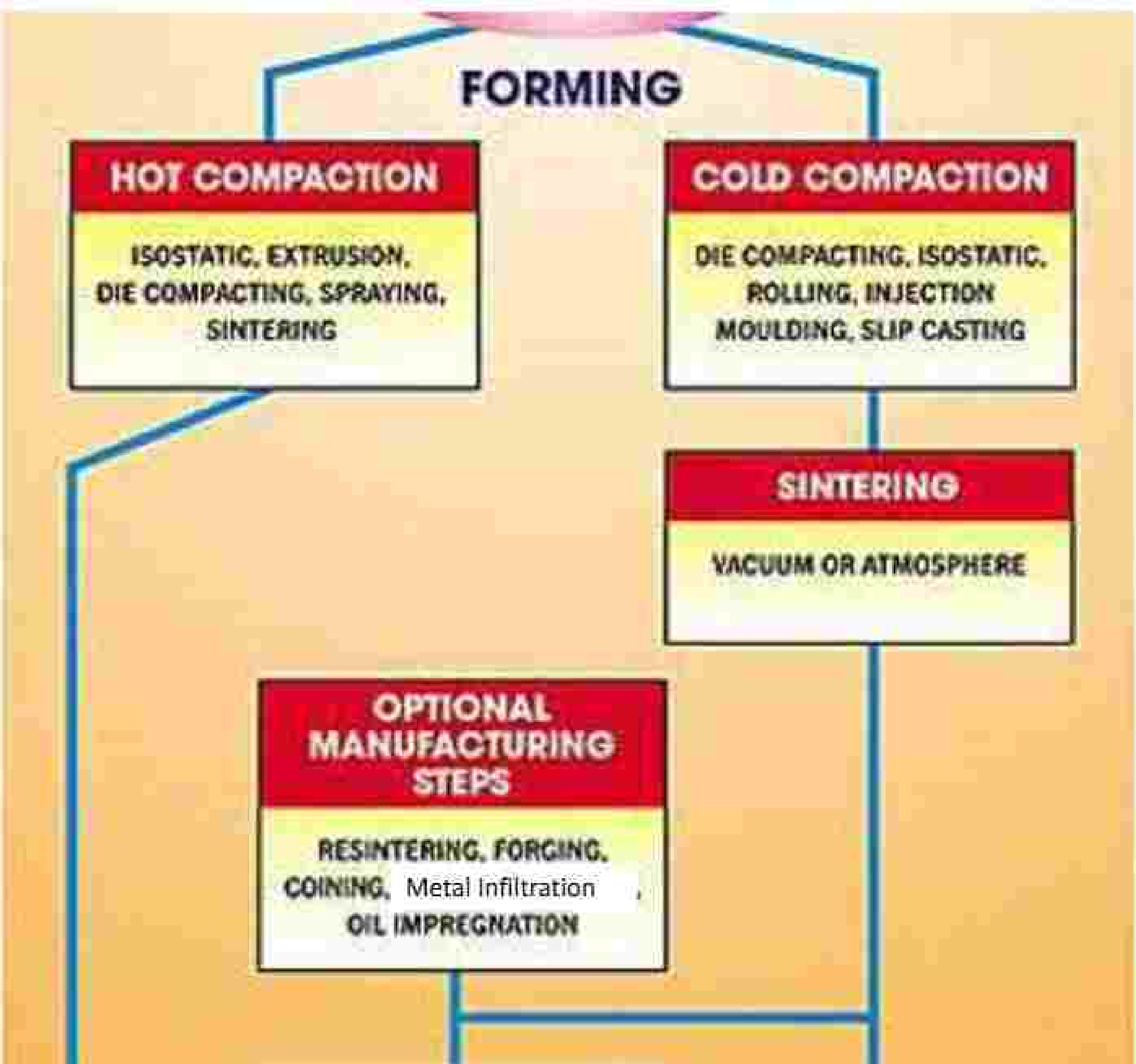
The compacted height can be expressed as a function of the height change ΔH from the initial height, which is the change in spacing between the upper and lower punches,

$$H = H_0 - \Delta H$$

giving the pressed density as a simple function of the change in punch spacing,

$$\rho_G = \frac{\rho_A H_0}{H_0 - \Delta H}$$

H = final compact height, m (convenient units: mm)
H_0 = initial powder fill height, m (convenient units: mm)
ΔH = height change from the initial height, m (convenient units: mm)
ρ_A = apparent density, kg/m^3 (convenient units: g/cm^3)
ρ_G = green density, kg/m^3 (convenient units: g/cm^3).


FORMING
HOT COMPACTION
ISOSTATIC, EXTRUSION, DIE COMPACTING, SPRAYING, SINTERING
COLD COMPACTION
DIE COMPACTING, ISOSTATIC, ROLLING, INJECTION MOULDING, SLIP CASTING
SINTERING
VACUUM OR ATMOSPHERE
OPTIONAL MANUFACTURING STEPS
RESINTERING, FORGING, COINING, Metal Infiltration , OIL IMPREGNATION

Additional Considerations During Compactir

- When the pressure is applied by only one punch, the maximum density occurs right below the punch surface and decreases away from the punch
- For complex shapes, multiple punches should be used

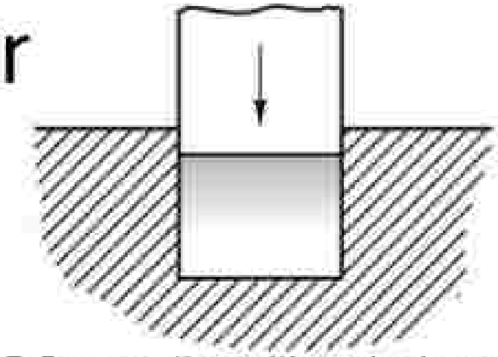


Figure 18-5 Compaction with a single moving punch, showing the resultant nonuniform density (shaded), highest where particle movement is the greatest.

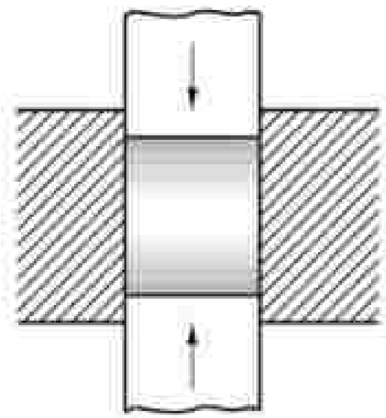
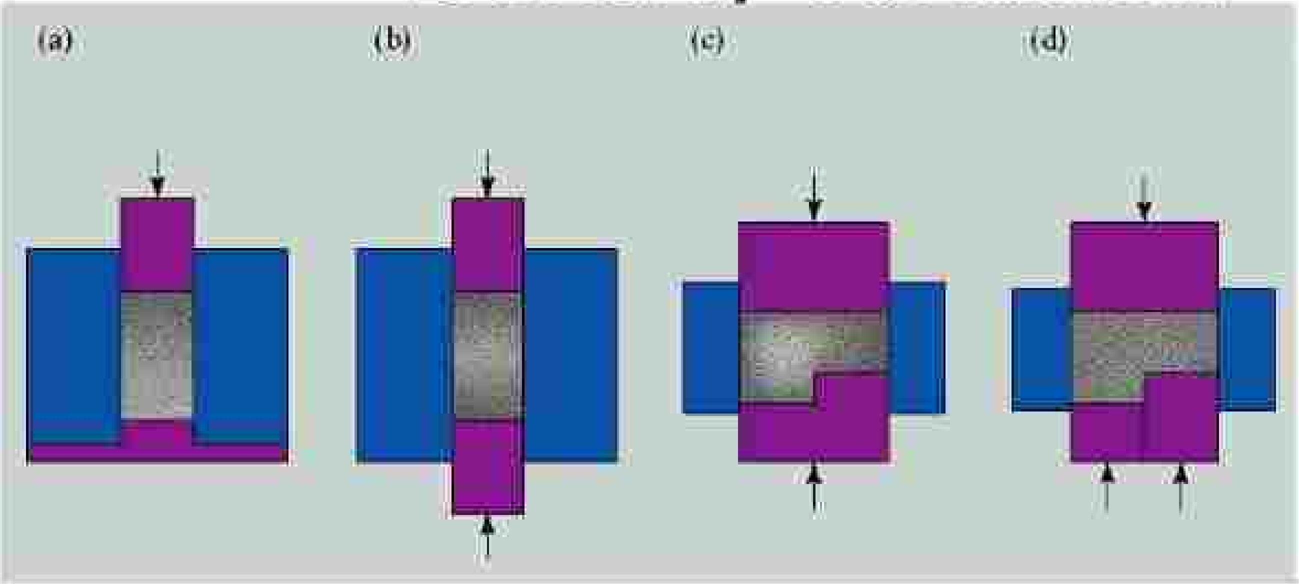


Figure 18-6 Density distribution obtained with a double-acting press and two moving punches. Note the increased uniformity compared to Figure 18-5. Thicker parts can be effectively compacted.

Density Variation



Density variation in compacting metal powders in different dies:

(a) and (c) single-action press

(b) and (d) double-action press.

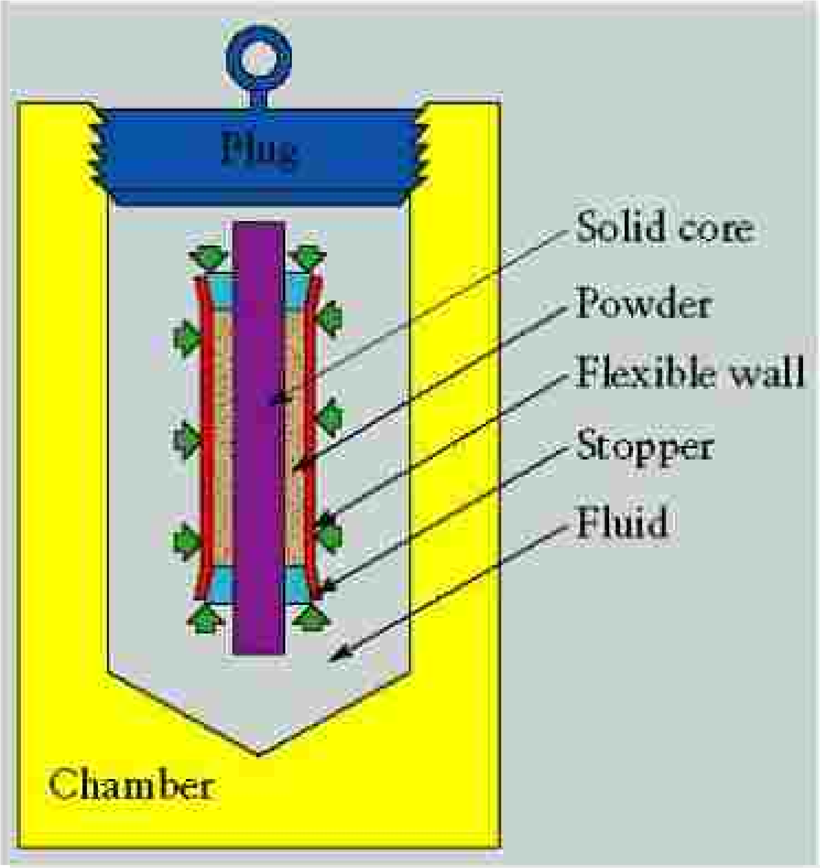
Note in (d) the greater uniformity of density in pressing with two punches with separate movements as compared with (c).

Generally, uniformity of density is preferred, although there are situations in which density variation, and hence variation of properties, within a apart may be desirable.

Complex Compacting

- If an extremely complex shape is desired, the powder may be encapsulated in a flexible mold, which is then immersed in a pressurized gas or liquid
  - Process is known as isostatic compaction
- In warm compaction, the powder is heated prior to pressing
- The amount of lubricant can be increased in the powder to reduce friction
- Because particles tend to be abrasive, tool wear is a concern in powder forming

Cold Isostatic Pressing(CIP)

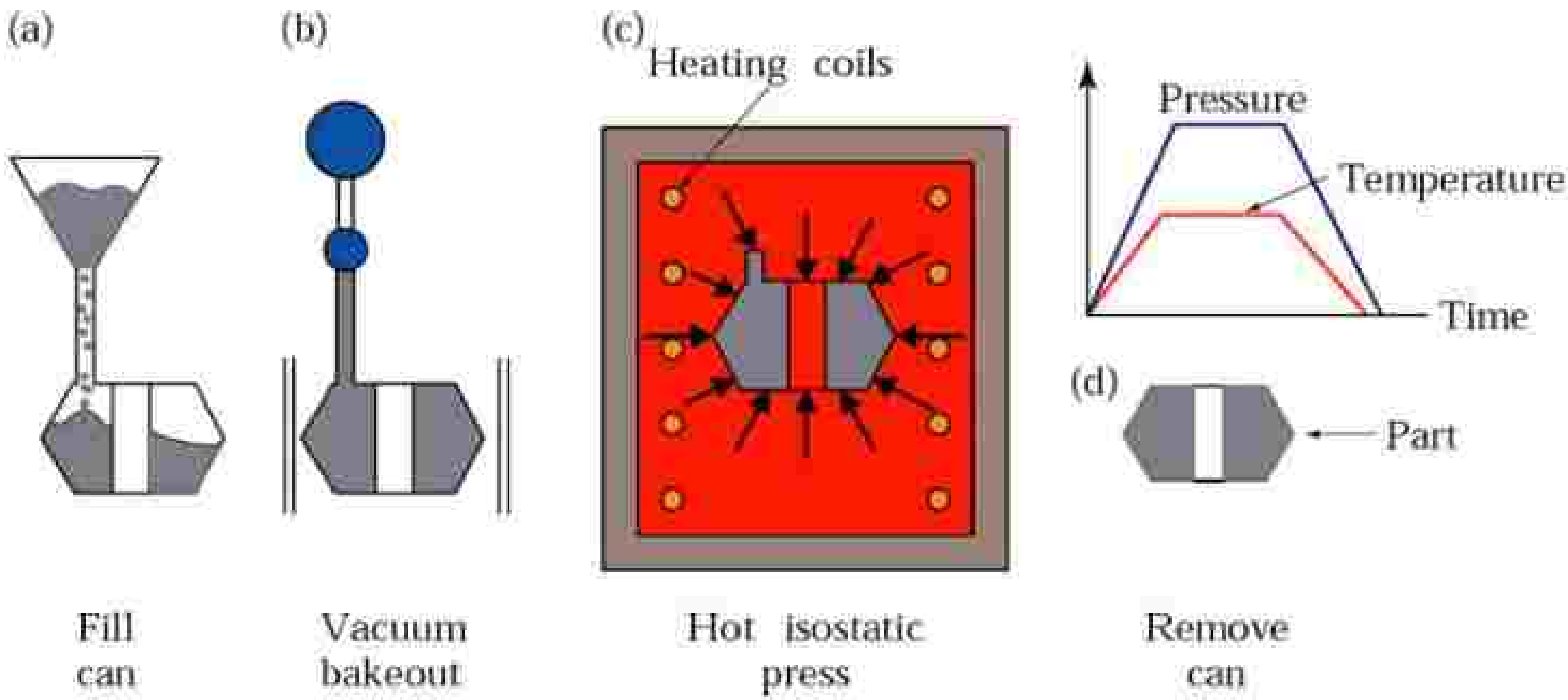


- Schematic illustration of cold isostatic pressing as applied to formation of a tube. The powder is enclosed in a flexible container around a solid core rod. Pressure is applied isostatically to the assembly inside a high-pressure chamber.

Hot-Isostatic Pressing

- Hot-isostatic pressing (HIP) combines powder compaction and sintering into a single operation
  - Gas-pressure squeezing at high temperatures
- Heated powders may need to be protected from harmful environments
- Products emerge at full density with unifrom, isotropic properties
- Near-net shapes are possible

Hot Isostatic Pressing(HIP)



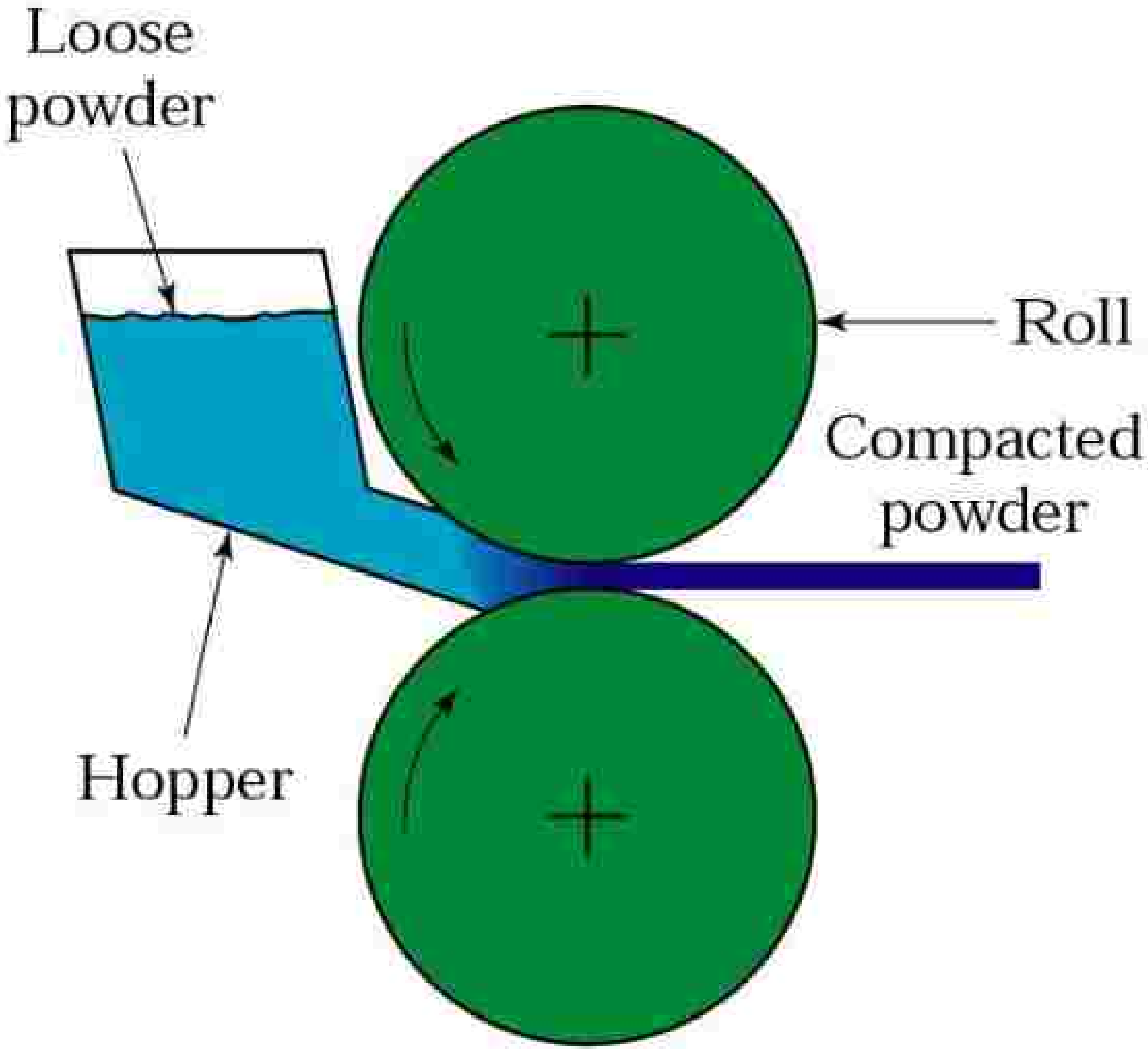
Other compacting and shaping operations

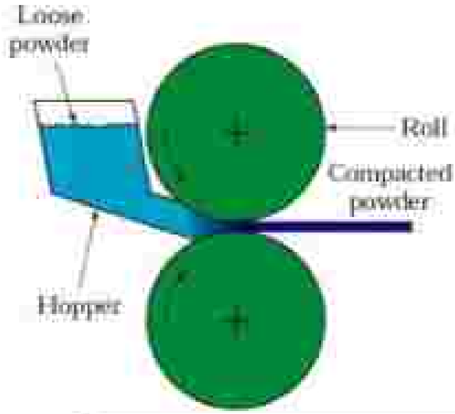
Rolling

Extrusion

Spray Deposition

Powder Rolling





نورد پودر به فشرده کردن پیوسته پودر فلزات به وسیله دستگاه نورد اشاره دارد.

در این پروسه، پودر فلزات از طریق قیف تغذیه میشوند تا ورق ها یا نوارهای خام (زینتر نشده) به روش پیوسته فشرده شوند.

بر روی مواد حاصل پروسه های بیشتری همچون زینتر کردن و نورد دوباره جهت ایجاد محصول نهایی انجام می شود.

می توان موادی با دانسیته بالا و یا با هر سایزی از تخلخل های دلخواه را تولید کرد.

نوارهای تولید شده با نورد کاری پودرها متعاقباً باعث تولید مواد تمیز و کاملاً یکنواخت با اندازه ذرات کوچک میشود.

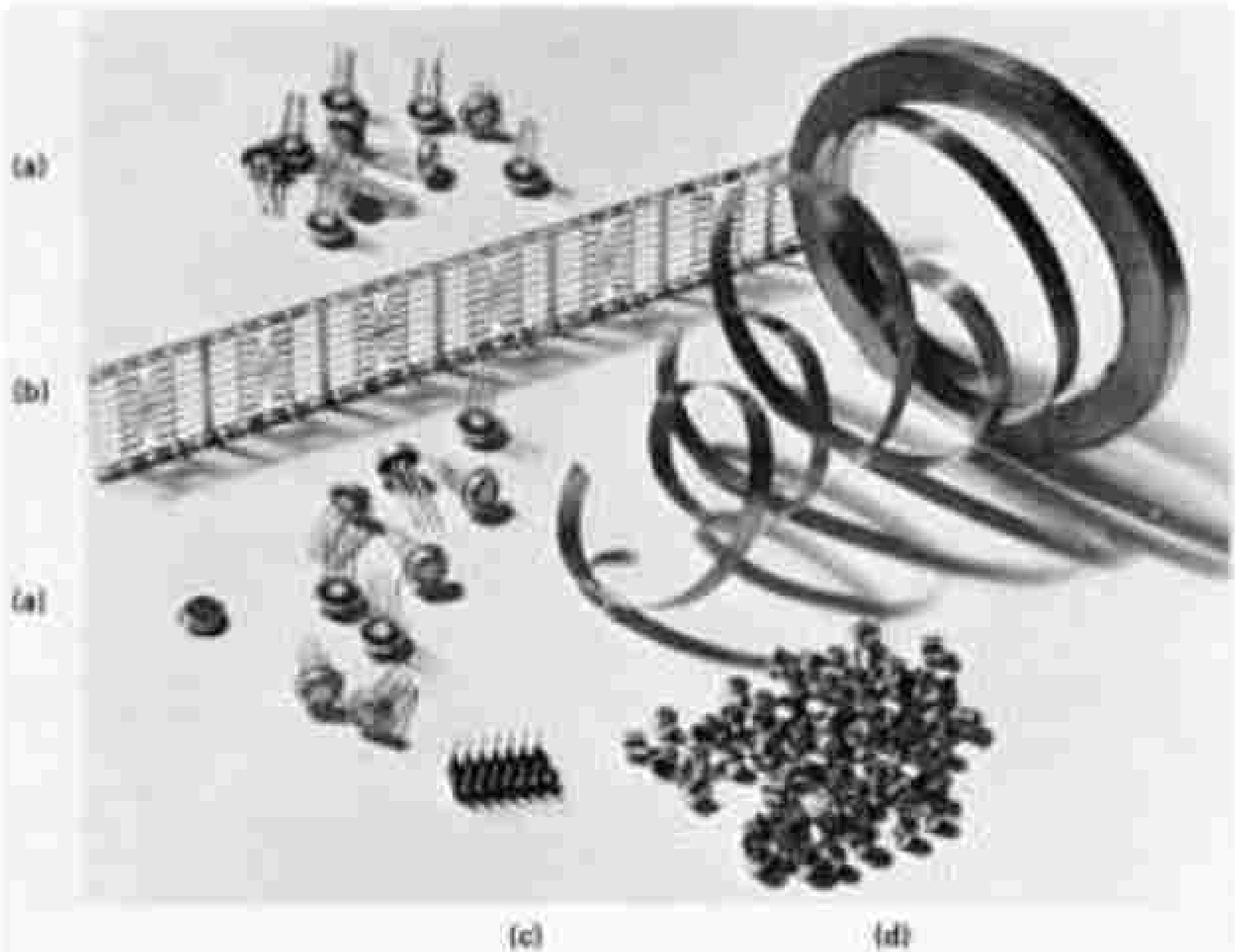
Reference:

Metals Hand book ,Powder Metallurgy, Vol.7, 9th edition, ASM,Metals Park OH, 1984.

کاربرد مواد نواری فشرده شده با نورد شامل:

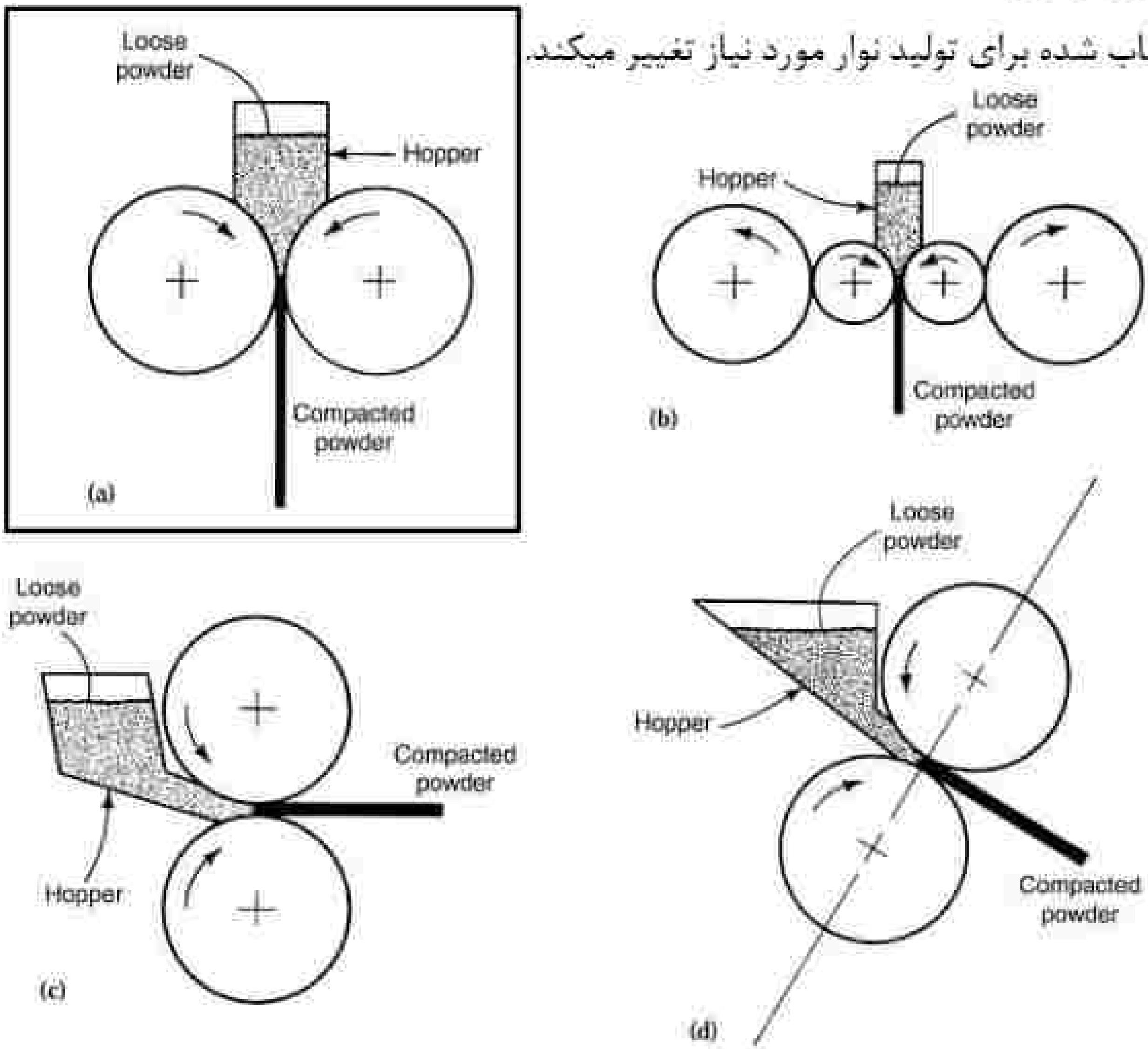
- قطعات نواری نیکلی با خلوص بالا برای باطری های تنظیم کننده ضربان قلب
- نوارهای آهن- نیکل
- قاب های هدایت کننده آهن- نیکل
- قوطی های Ni- Fe- Co
- نوارهای کامپوزیتی Al- Sic
- فویل های Ti- Al برای تولید کامپوزیت
- نواری Ni- Ti برای کاربردهای حافظه داری

نمونه هایی ازکاربرد نوارهای نیکل فشرده شده



روند تولید: ۱.وضعیت غلتک ها

نوع و موقعیت غلتک ها با نوع سیستم انتخاب شده برای تولید نوار مورد نیاز تغییر میکند.



غلتک ها می توانند به صورت:

- عمودی (همانند نوارهای سنتی)
- افقی و یا
- با شیب زاویه دار قرار گیرند.

انتخاب موقعیت غلتک ها با فاکتورهای گوناگون تعیین میشود:

- خصوصیات مواد.
- مقدار نواری که بایستی تولید شود.
- محصول نهایی مورد نظر.
- ساختار مخصوص مورد نیاز.

Reference:

Metals Hand book ,Powder Metallurgy, Vol.7, 9th edition, ASM,Metals Park OH, 1984.

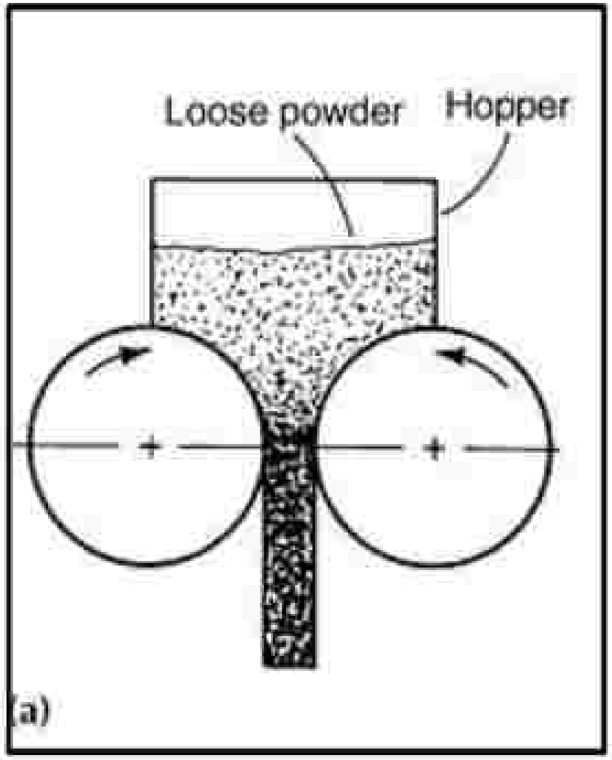
۲.تغذیه پودر

قدم ابتدایی در پروسه فشرده سازی با نورد، تغذیه پودر به درون غلتک هاست.

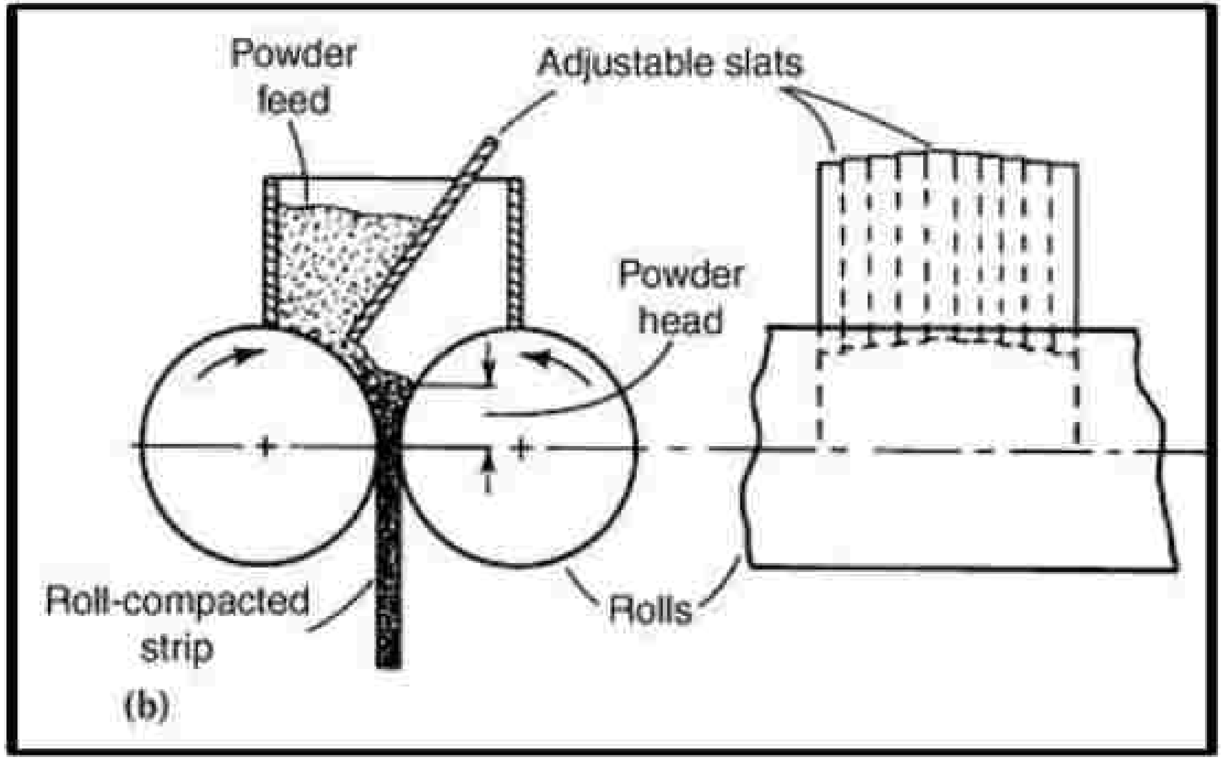
نوار خام بایستی دانسیته یکنواختی را از یک لبه تا لبه دیگر از خود نشان دهد.

دو روش تغذیه به غلتک نوردها

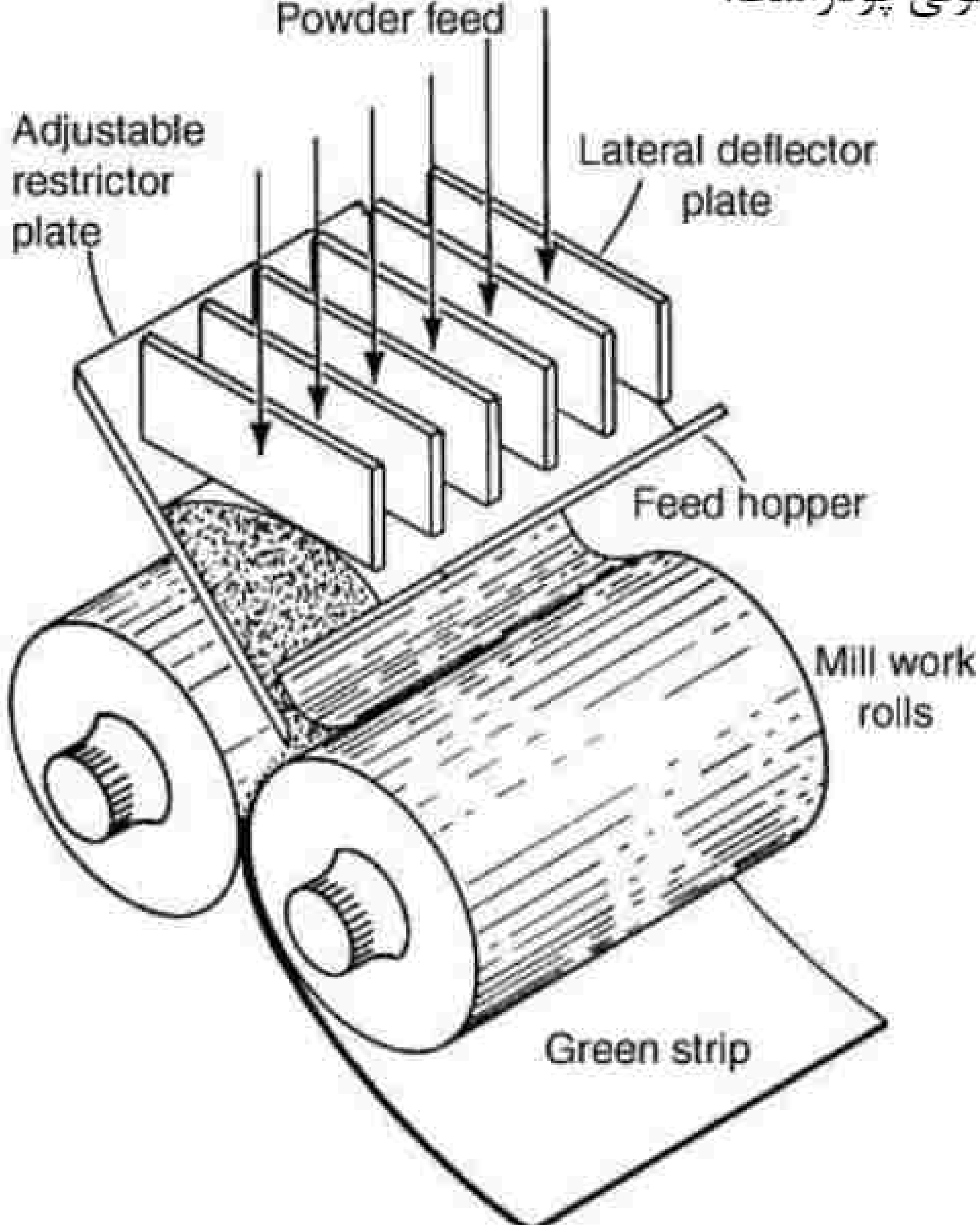
a تغذیه اشباع



b تغذیه غیراشباع



این شکل بیانگر یک تغذیه کننده معمولی پودراست.

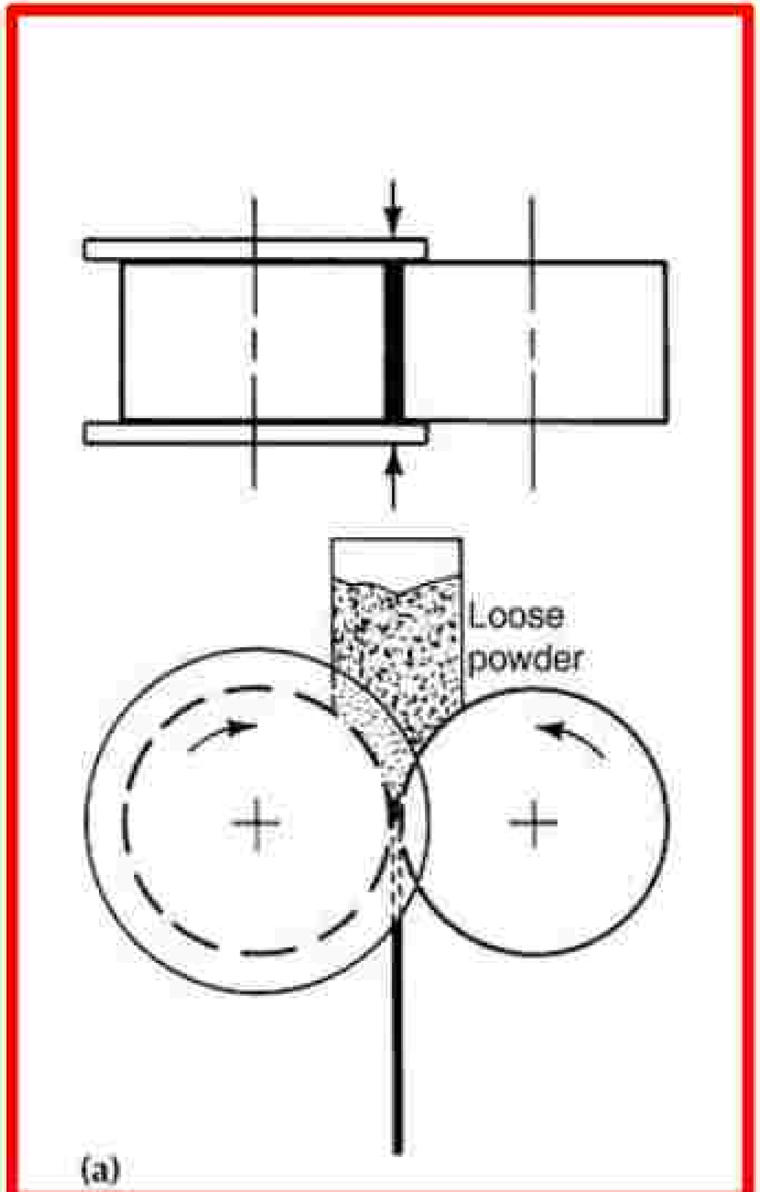


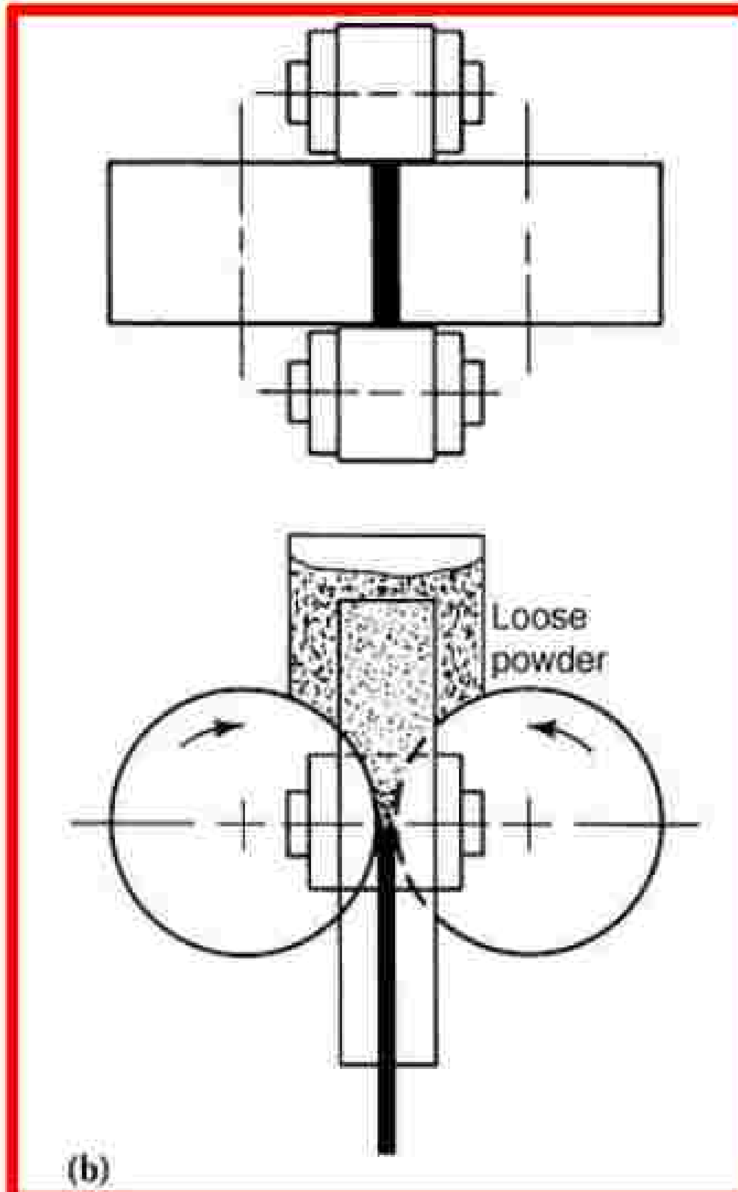
در این نوع طراحی پودر به صورت هموار در عرض قیف پخش می شود.

روشهای حفظ پودر در درون شکاف غلتک ها

۳.کنترل لبه

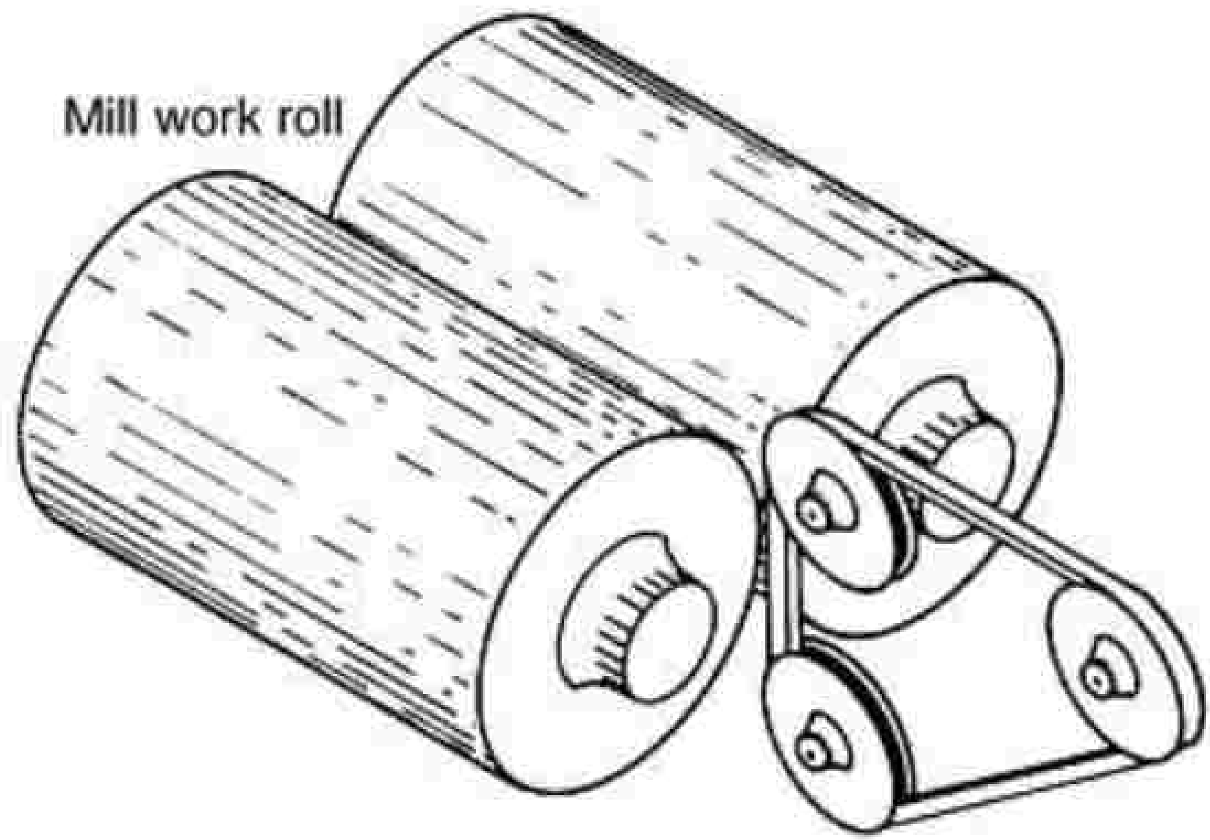
نوار خام نورد شده از پودر بایستی ضخامت و دانسیته یکنواخت در عرض را دارا باشد.
همچنین لبه های آن بایستی به خوبی شکل گرفته و به اندازه وسط نوار دانسیته داشته باشد.





تسمه پیوسته که شکاف ها را در لبه های غلتک می پوشاند نیز روش مؤثری برای جلوگیری از در رفتن پودر است .

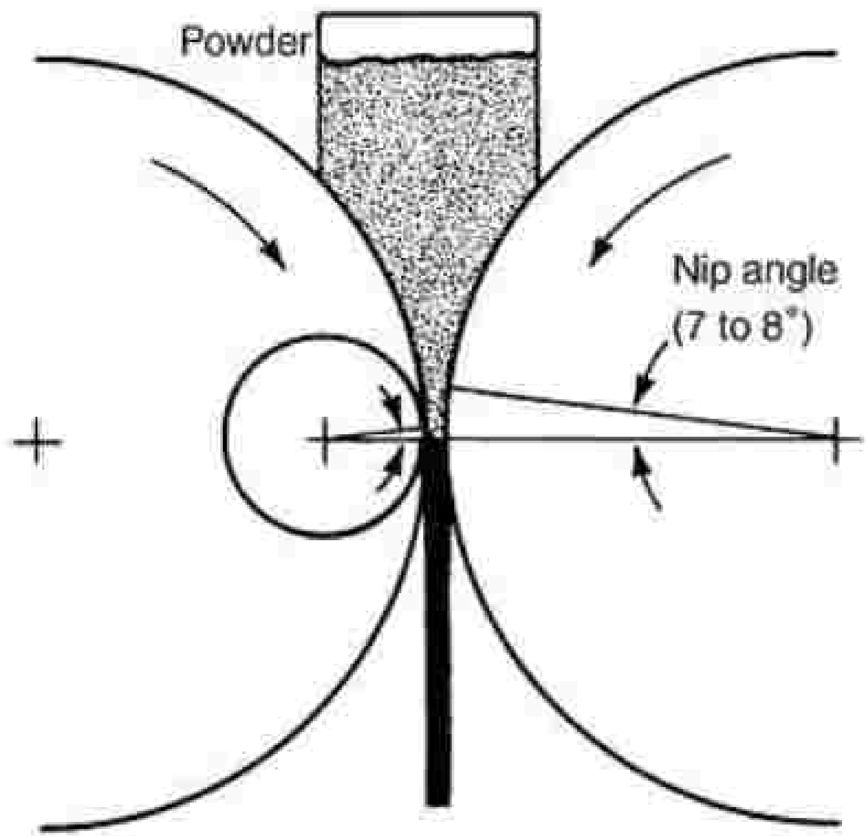
سیستم های دیگری نیز وجود دارند که نوارهایی با لبه های محکم ایجاد می کنند که نیازمند کمی پلیسه برداری در لبه ها خواهد بود.



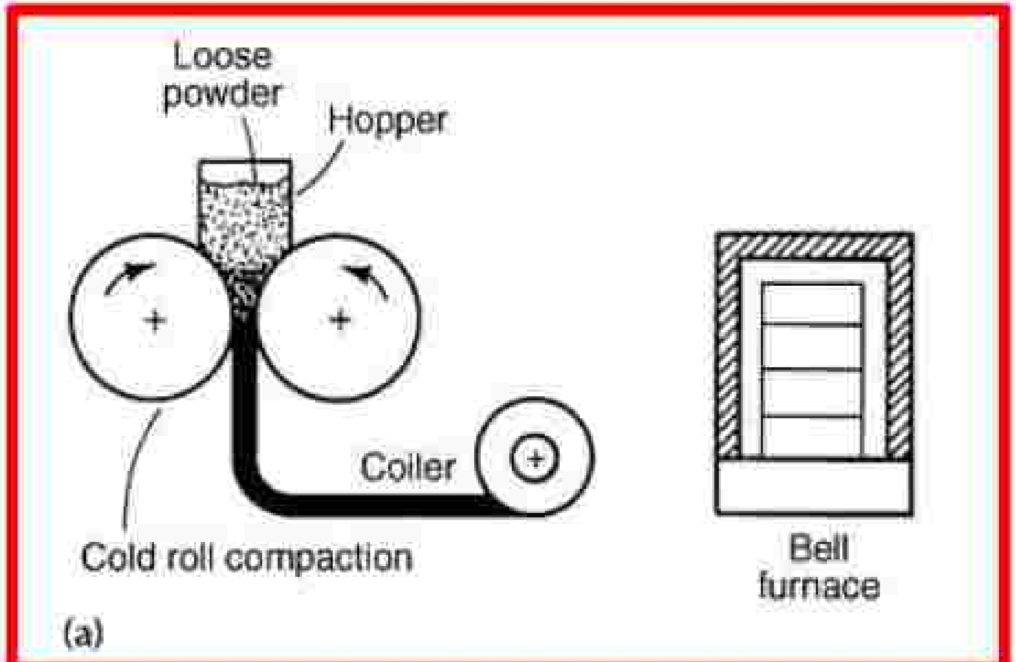
۴.قطر غلتک

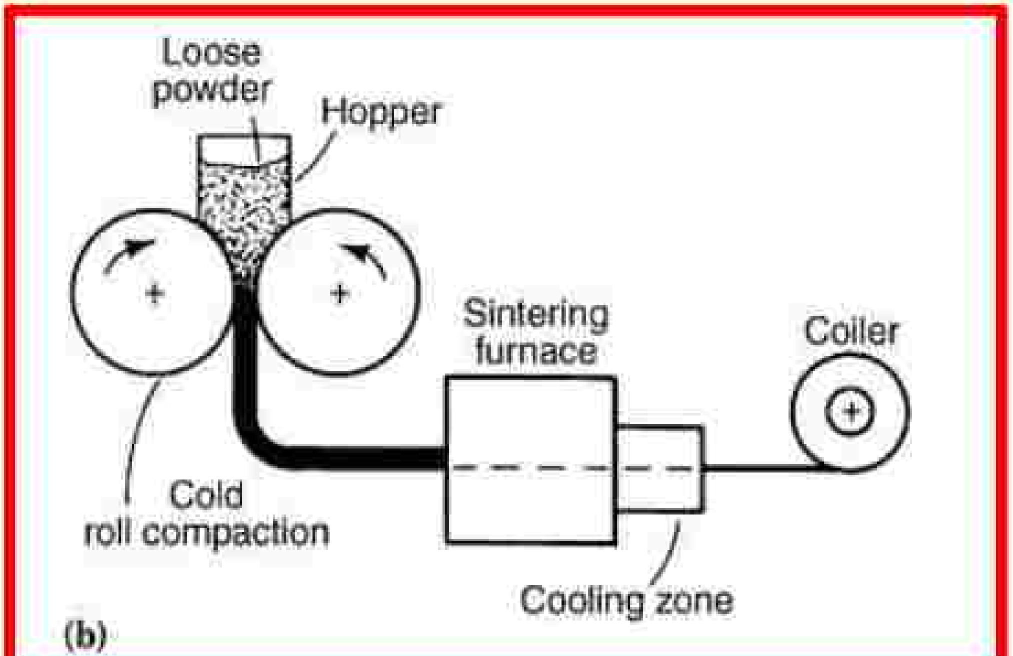
در نورد پودر، ضخامت نوار عمدتاً توسط قطر غلتک مورد استفاده تعیین میشود. قطر غلتک از mm ۷/۱۲-۹۲۰ تغییر می کند .

زاویه گاز گرفتگی مورد استفاده د ر مورد نورد پودر همچون زاویه در نورد فلز معمولی می باشد در حدود .توجه داشته باشید که قطر غلتک های بزرگ قوس بزرگتری در روی سطح غلتک به وسیله زاویه گاز گرفتگی ایجاد میشود.



دو روش جابجائی نوار –
زمانیکه فشرده سازی با نورد سرد انجام گرفته است.





۵.عملیات تکمیلی

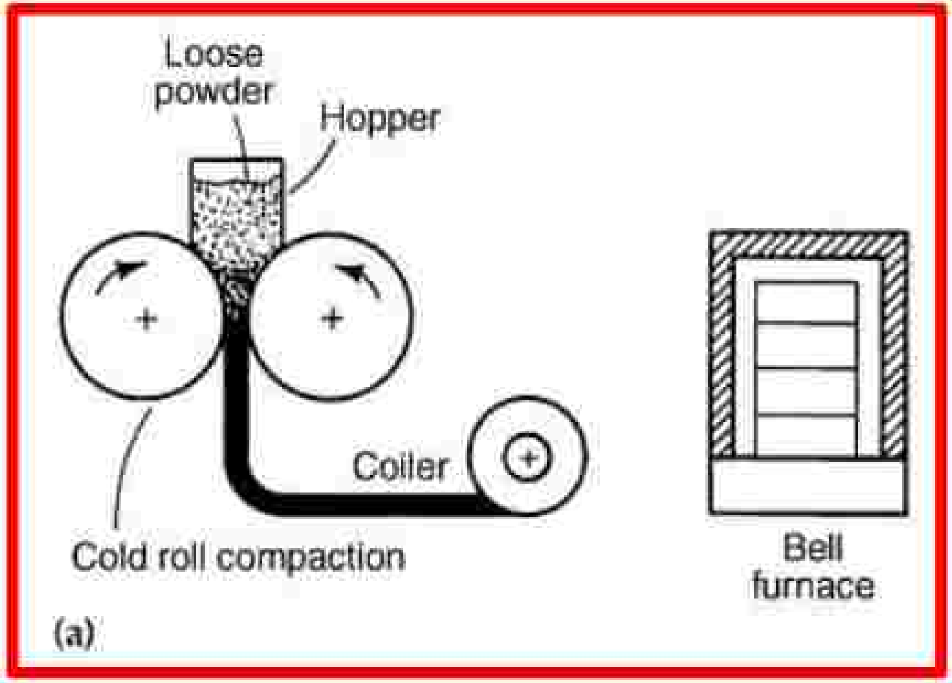
نوار خام یکنواخت تولید شده به وسیله غلتک فشرده سازی، بایستی قبل از دوباره فشرده سازی بیشتر زینتر شود.

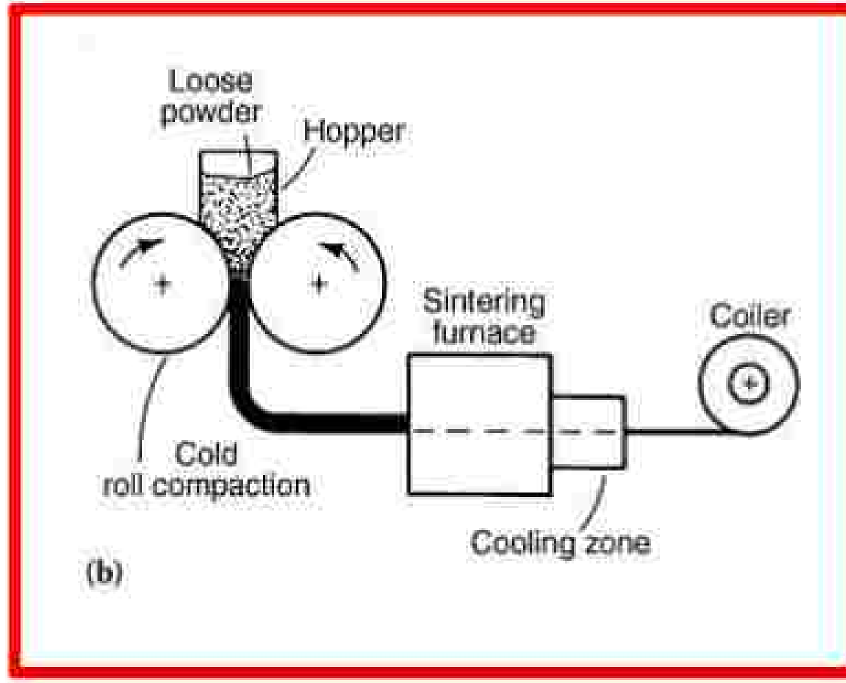
دانسیته خام معمولاً مابین٪ ۹۰ ۷۵ دانسیته تئوری است .

۵.عملیات تکمیلی

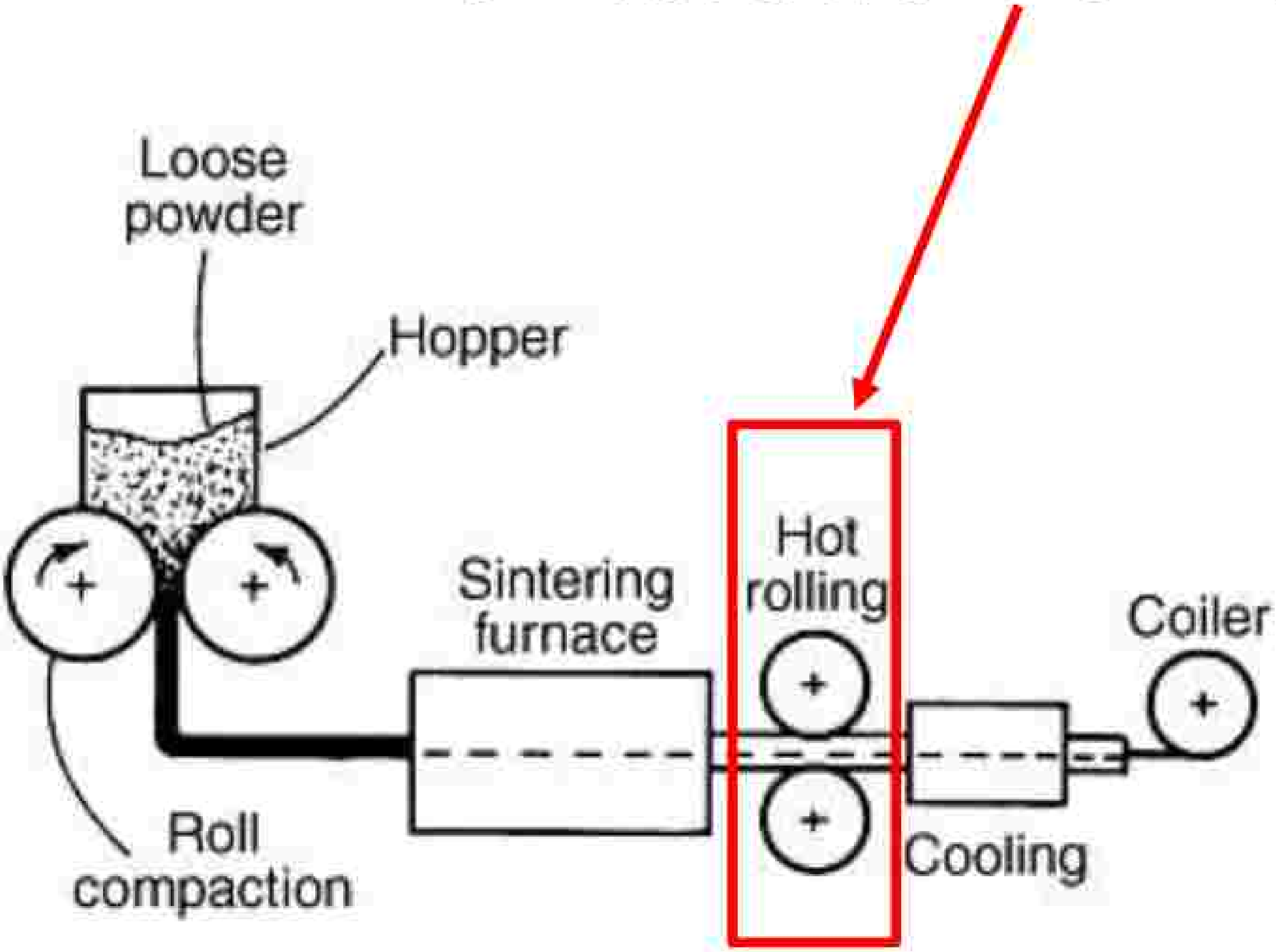
نوار خام یکنواخت تولید شده به وسیله غلتک فشرده سازی بایستی قبل از دوباره فشرده سازی بیشتر زینتر شود. دانسیته خام معمولاً مابین۹۰٪ ۷۵ دانسیته تئوری است.

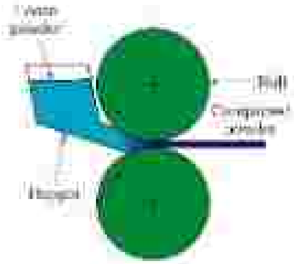
دو روش جابجائی نوار زمانیکه فشرده سازی با نورد سرد انجام گرفته است.





در شکل زیر نوار حاصله از نورد، از میان کوره زینتر عبور می کند در حالیکه هنوز گرم است نورد گرم برای حصول دانسیته کامل انجام شده و سپس نوار سرد و پیچیده میشود.

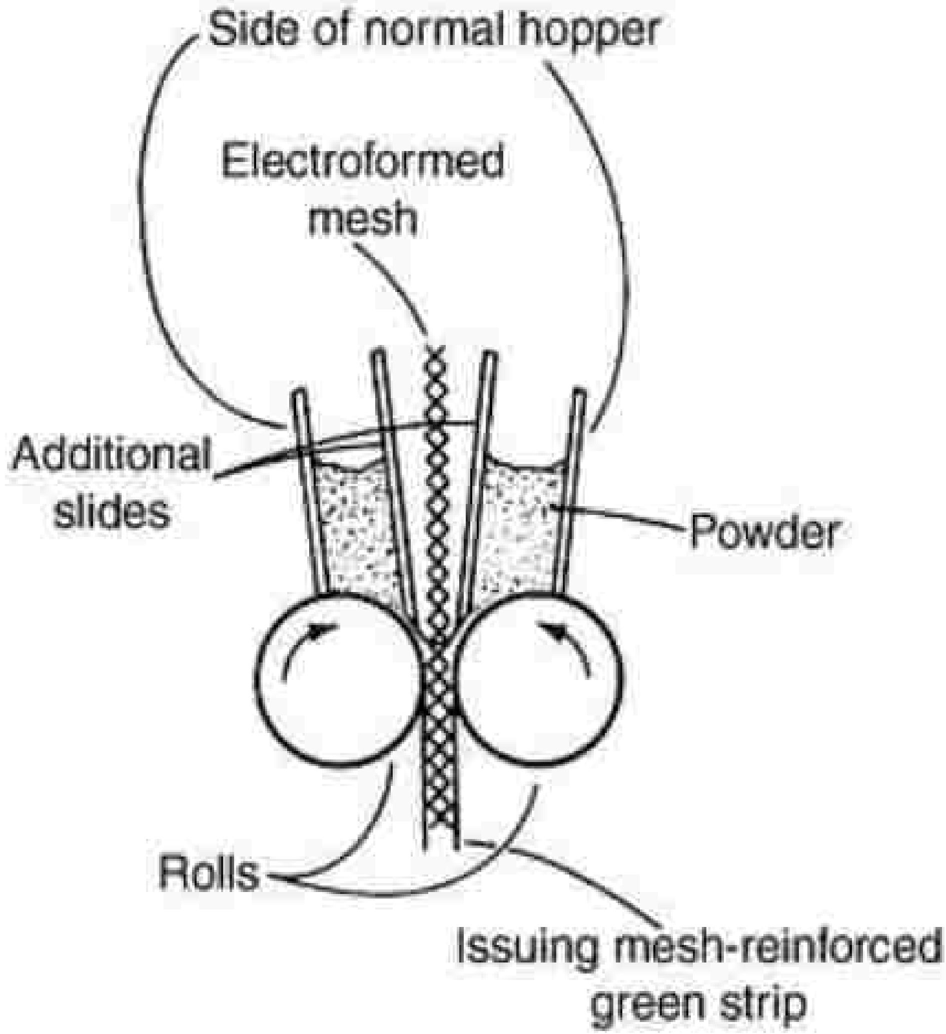




تولید تجاری

از سال ۱۹۵۸-۱۹۶۸ پروسه نورد پودر توجه قابل ملاحظه ای را در بریتانیا ، آمریکا ، کانادا ، شوروی و ژاپن جلب کرد و یک مرکزی بنا شد تا پروسه های کم قیمت را جهت تولید پودر فلزاتی همچون Al, Fe, Cu, Ni با پروسه های نورد پودر ترکیب کند و روشهای تولید ورق های نازک و لوله ها با شرایط اقتصادی تر گسترش یابند.

شکل زیر نشانگر روشی برای تولید نوارهای متخلخل از نیکل خالص برای باطری های قلیائی و سوخت سلولهای الکترونی است. در این روش، مش فرم داده شده در قیف پودر جاگذاری می شود تا به درون نوار نورد شده جا داده شود و الکترود متخلخل بالایی با استحکام خام کافی تولید شود.

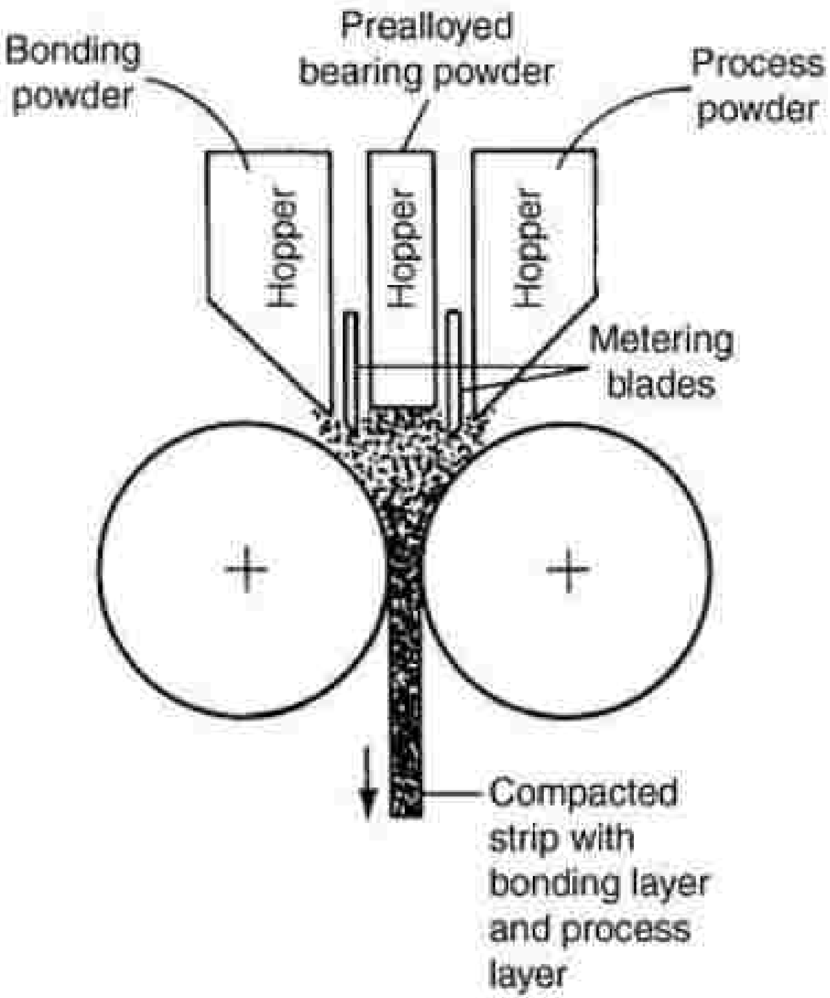


یاتاقان کامپوزیتی

- فشردن با نورد همچنین می تواند برای تولید کامپوزیت استفاده شود.
- مثالی از این مواد کامپیوزیت فشرده شده با نورد، نوارهای بای متال که در تولید خود و یا میله انتقال یاتاقان استفاده میشود، میباشد.
- تغییرات در استاندارد وسایل مربوط به اتومبیل منجر به جایگزین شدن این مواد جدید به جای ترکیبات روپوش یاطاقان مس– سرب سنتی شد.
- نوار نورد شده شامل لایه ای از Al-8.5Pb-4Si- 1.5Sn-1Cu از پودرهای از قبل آلیاژ شده است که بر روی لایه آلومینیوم خالص نورد میشود .

تولید فشرده سازی با نورد برای ایجاد کامپوزیت درشکل زیر آمده است.

- سه تا قیف پودر و تیغه های کنترل کننده جریان پودر مورد نیاز است.
- این تیغه ها جریان پودر را به درون شکاف نورد کنترل می کنند.
- سیم پیچ نوار کامپوزیت ایجاد شده سپس زینتر میشود.



ذوب پودربرای تولید یاتاقان کامپیوزیتی

یک کوره ذوب القائی توسط آلومینیوم و مس و سیلیکون عنصری شارژ میشود. در دمای بالاتر از دمای متوسط، سرب و قلع به درون مذاب افزوده میشود. دمای کوره تا دمای تک فازی بالا برده میشود کمی بیشتر گرم میشود تا حد اطمینان تأمین شود. جریان هدایتی کوره موجب عمل هم زنی میشود که باعث ایجاد اطمینان از حل شدن قلع و سرب میشود تا یک محلول تک فازی واقعی ایجاد شود .

اتمیزه کردن

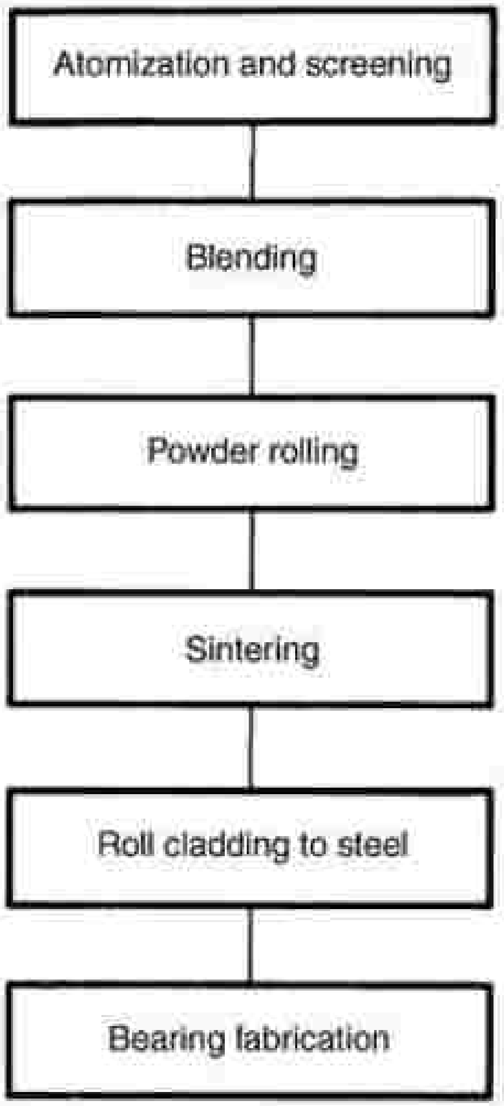
جریان نازک فلز به صورت عمودی به درون محفظه اتمیزاسیون ریخته میشود که در آنجا ذرات مجزا شکسته شده و سریعا منجمد میشود. ذرات پودر به درون جمع کننده ای با ۶متر ارتفاع و ۱ متر قطر جمع میشود و سپس آنها از میان یک جدا کننده عبور می کنند تا ذرات ریز و درشت از هم جدا شده و ذرات خارج از محدوده را خارج کنند .

ترکیب

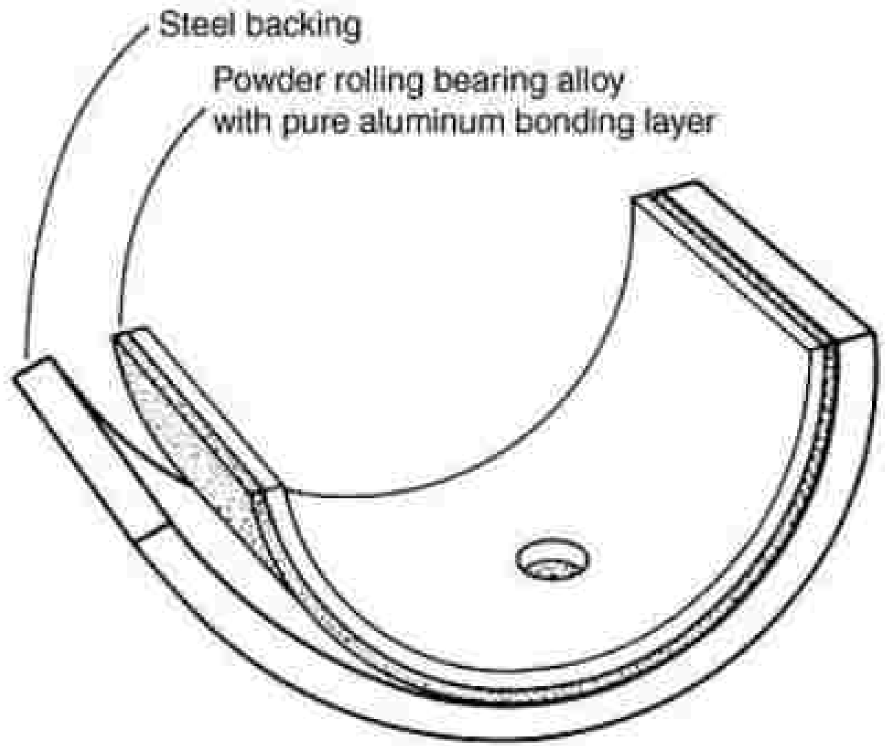
روش ترکیبی برای تولید نوار از پیش آلیاژی شده آلومینیوم و آلیاژ سرب انتخاب شده است که در نهایت به پشت فولاد کم کربن، نوار را نورد می کنند.

- تجربه قبلی برای یاطاقان های با پایه آلومینیوم کار شده ثابت می کند که آنها برای اتصال مستقیم به سطح فولاد غیرمناسب هستند.
- زمانیکه آلیاژ آلومینیوم با فازهای نرمی همچون سرب یا قلع مستقیماً به فولاد پیوند می خورد، پیوند واسطه لزوماً شامل بی منظمی های میکروسکوپی است واین بی منظمی ها در جاهائی که رسوبات قلع و سرب در تماس مستقیم با فولاد هستند اتفاق می افتد.
- این نقص باعث ایجاد تردی در سطح شده و به عنوان مکان هایی جهت تسریع در پیشروی ترک خستگی شده وباعث جدا شدن پیوندها تحت شرایط کاری میشود.
- در نتیجه آلیاژهای آلومینیوم کار شده شامل مقدار قابل توجهی فاز نرم است که تقریباً همیشه با لایه پیوندی آلومینیوم یا نیکل خالص در مقابل فولاد استفاده میشوند.

نمودار تولید یاطاقان های روکش دار با نورد پودر

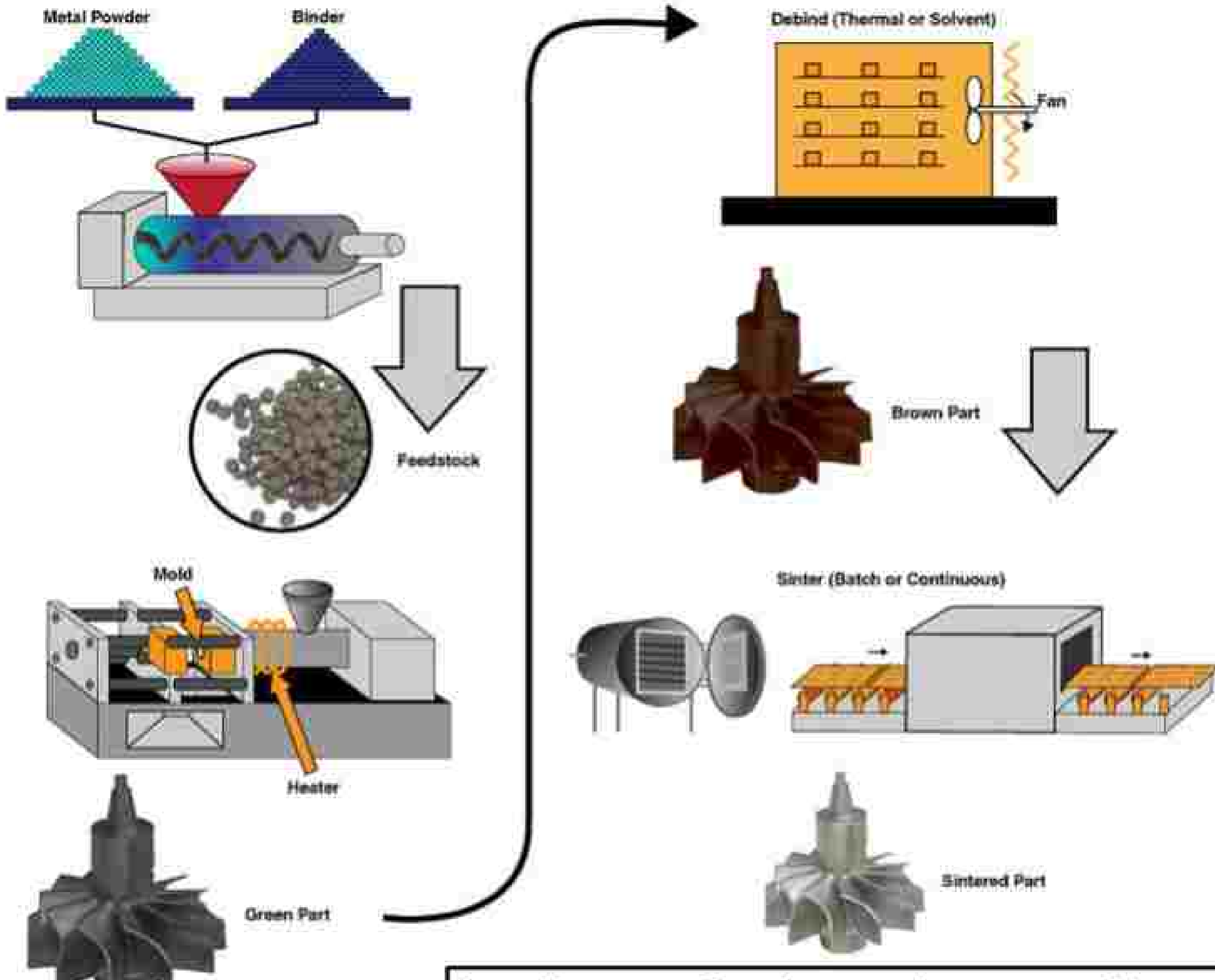


(a)



(b)

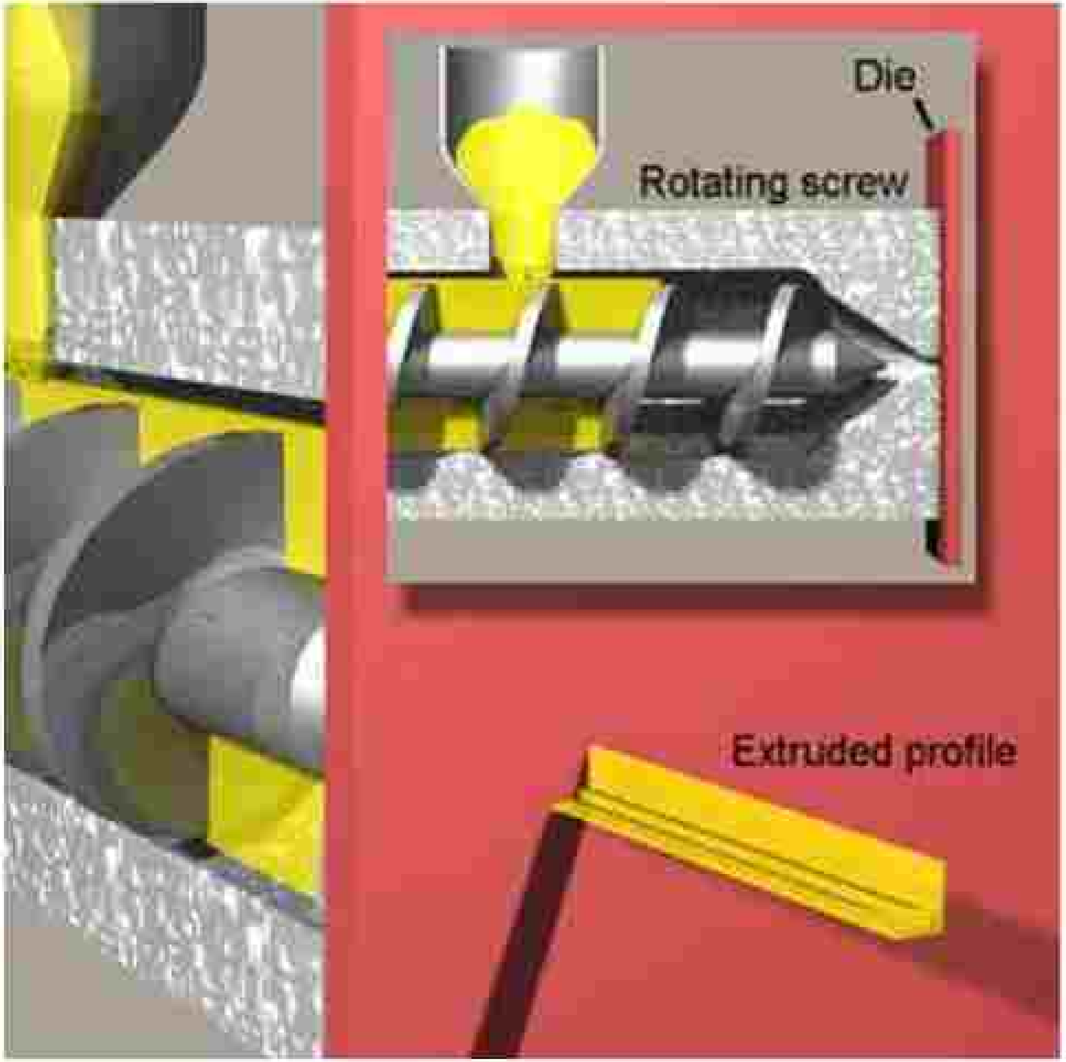
METAL INJECTION MOLDING PROCESS



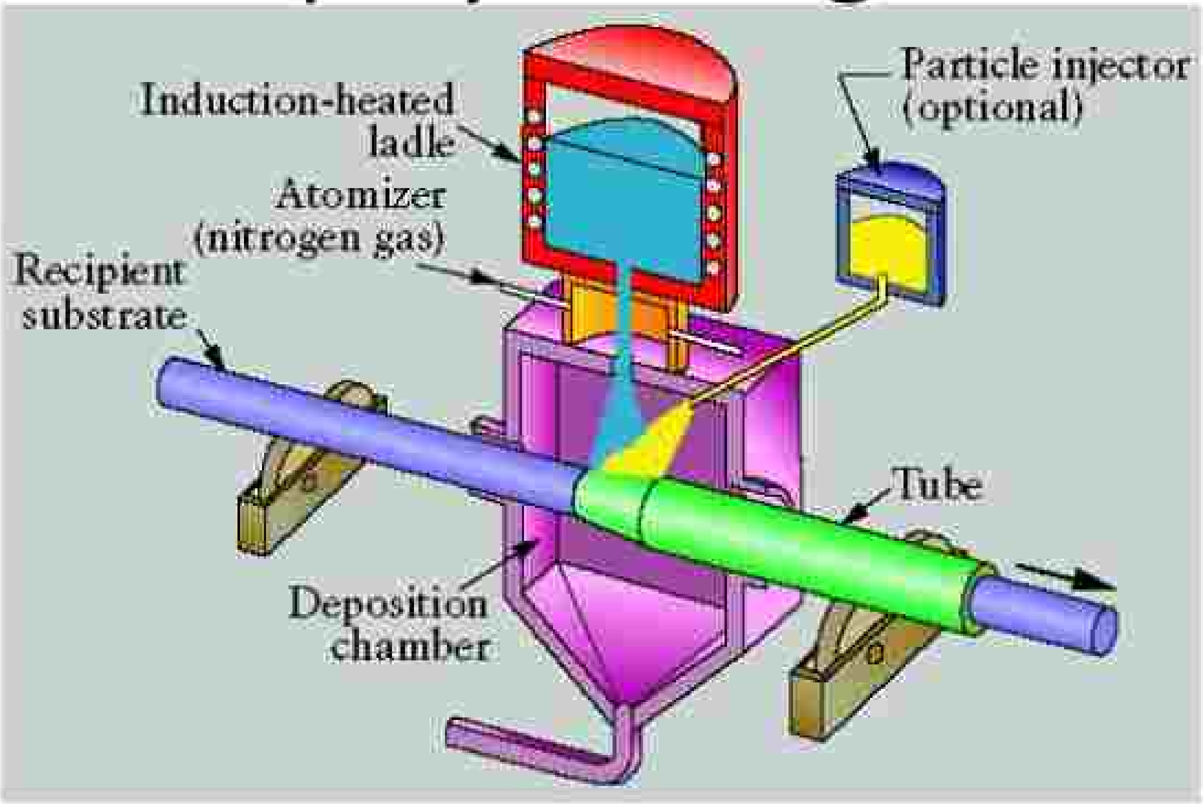
http://www.mpif.org/IntroPM/injection-molding.asp

ERASTEEL

Powder Extrusion



Spray Casting

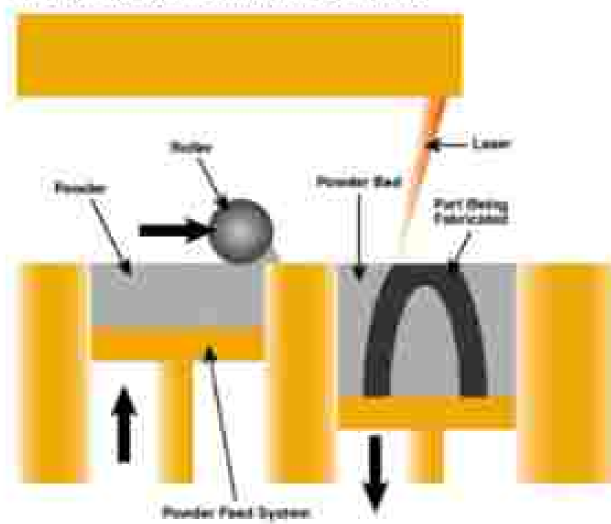


Spray casting (Osprey process) in which molten metal is sprayed over a rotating mandrel to produce seamless tubing and pipe..

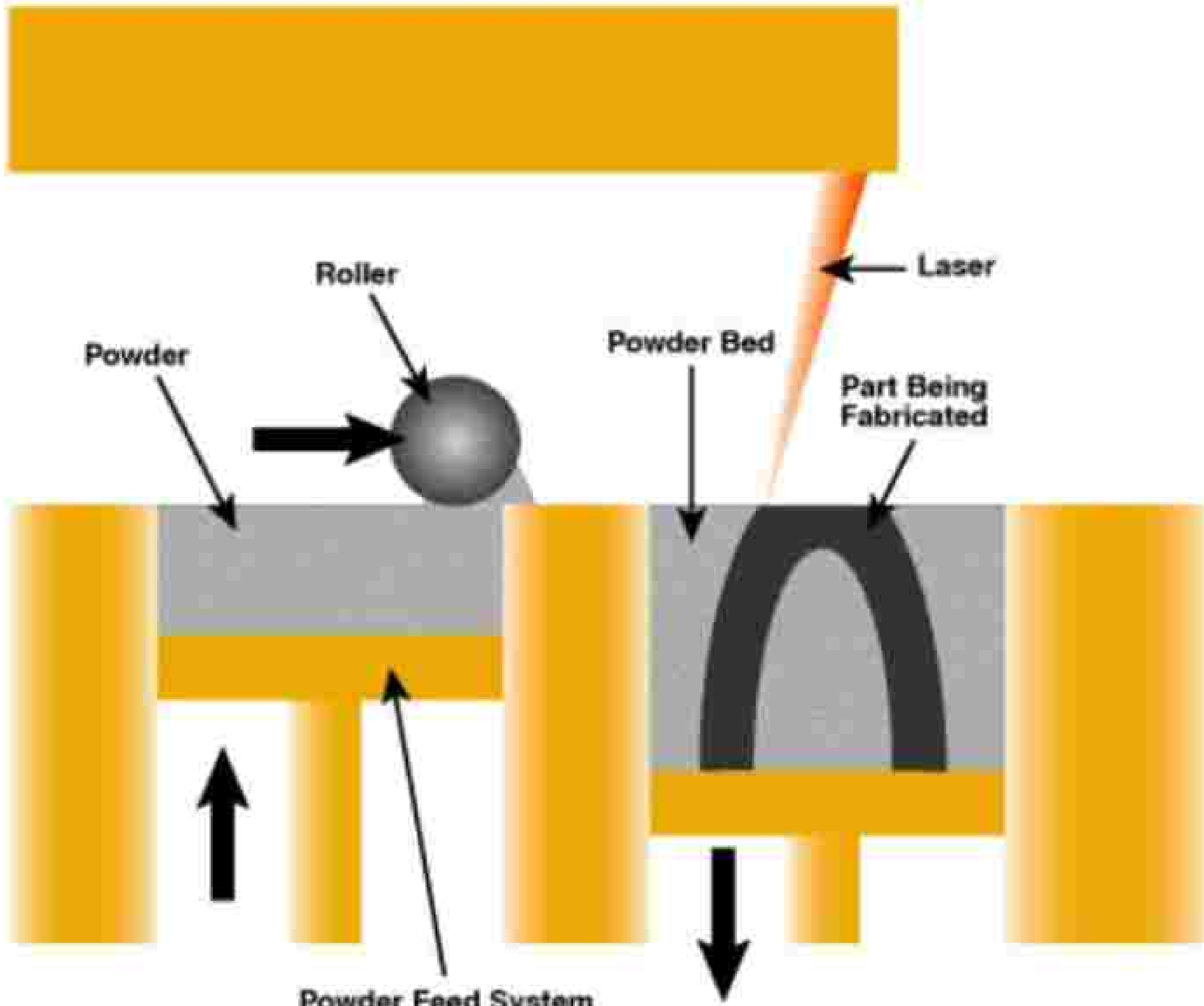
Metal Additive Manufacturing

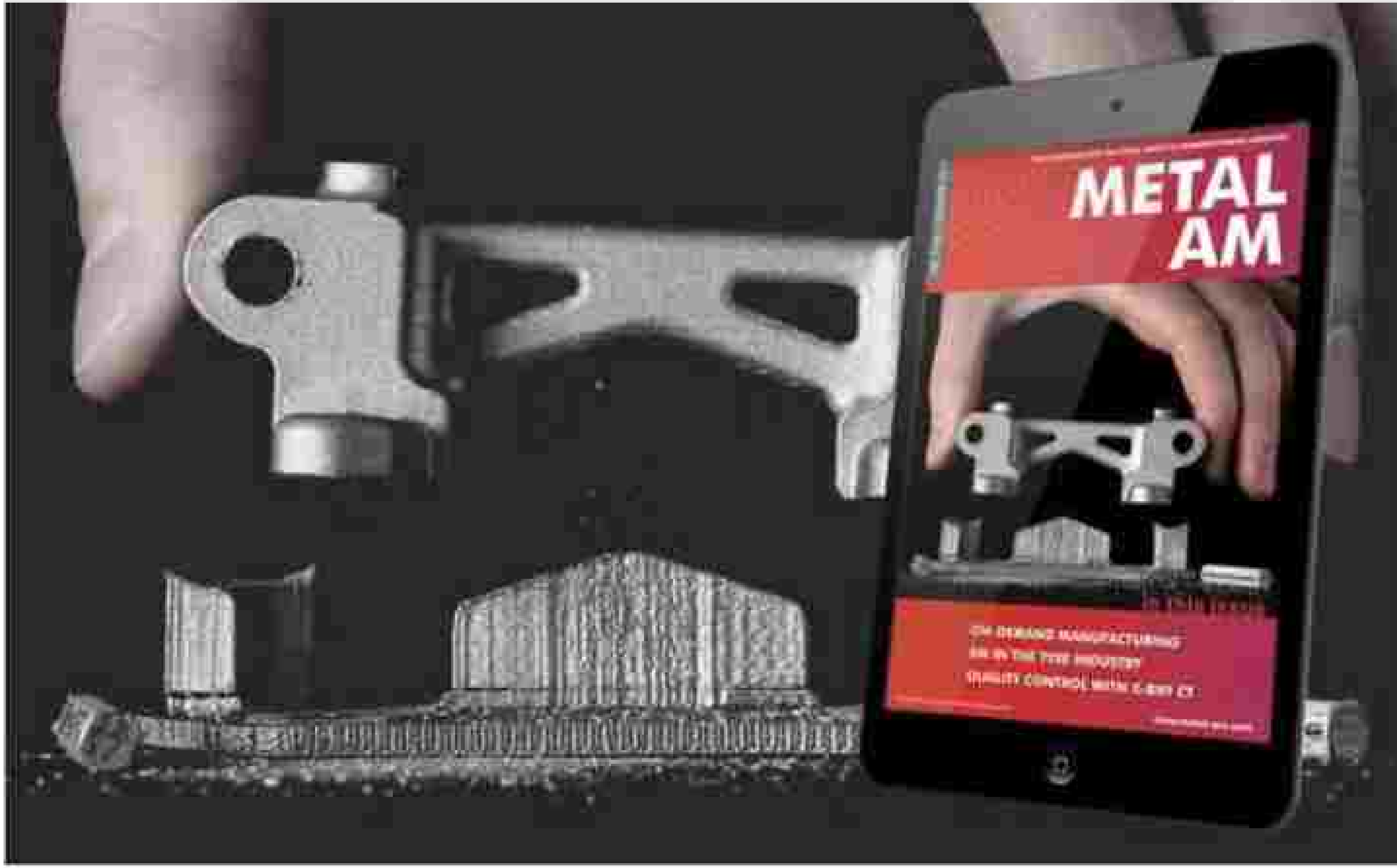
Metal additive manufacturing (MAM), or metal 3D printing, has the potential to profoundly change the production, time-to-market, and simplicity of components and assemblies. Unlike conventional or subtractive manufacturing processes, such as drilling, which creates a part by removing material, additive manufacturing builds a part using a layer-by-layer process directly from a digital model, without the use of molds or dies that add time, waste material, and expense to the manufacturing process. Additive manufacturing has been used as a design and prototyping tool for decades, but the focus of additive manufacturing is now shifting to the direct production of components, such as medical implants, aircraft engine parts, and jewelry.

METAL ADDITIVE MANUFACTURING

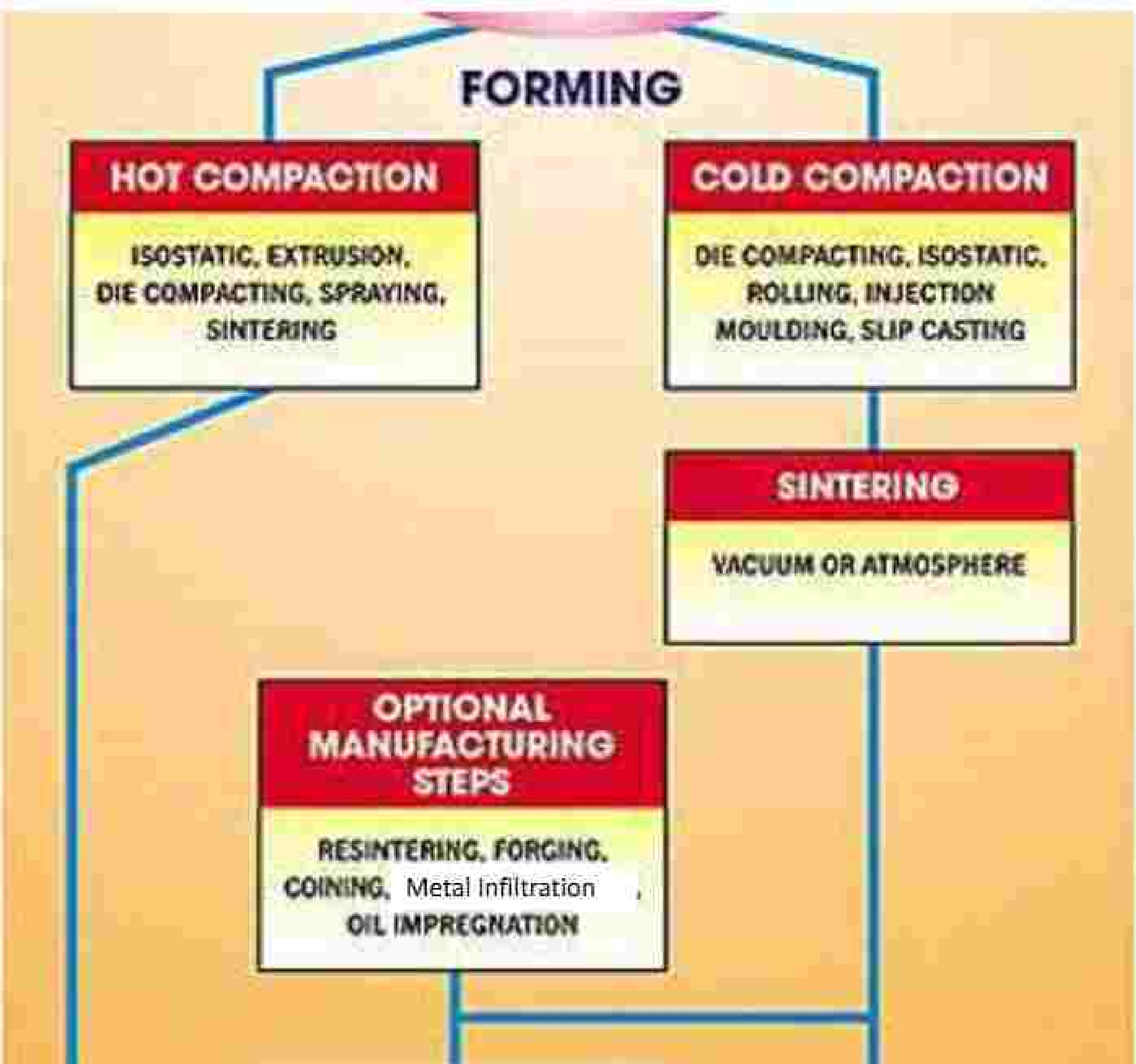


METAL ADDITIVE MANUFACTURING



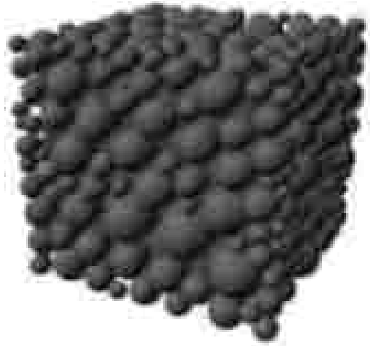


http://www.metal-am.com/metal-additive-manufacturing-magazine/


FORMING
HOT COMPACTION
ISOSTATIC, EXTRUSION, DIE COMPACTING, SPRAYING, SINTERING
COLD COMPACTION
DIE COMPACTING, ISOSTATIC, ROLLING, INJECTION MOULDING, SLIP CASTING
SINTERING
VACUUM OR ATMOSPHERE
OPTIONAL MANUFACTURING STEPS
RESINTERING, FORGING, COINING, Metal Infiltration, OIL IMPREGNATION

Powder Compaction and Sintering

Raw powder



Formed product

Sintered product

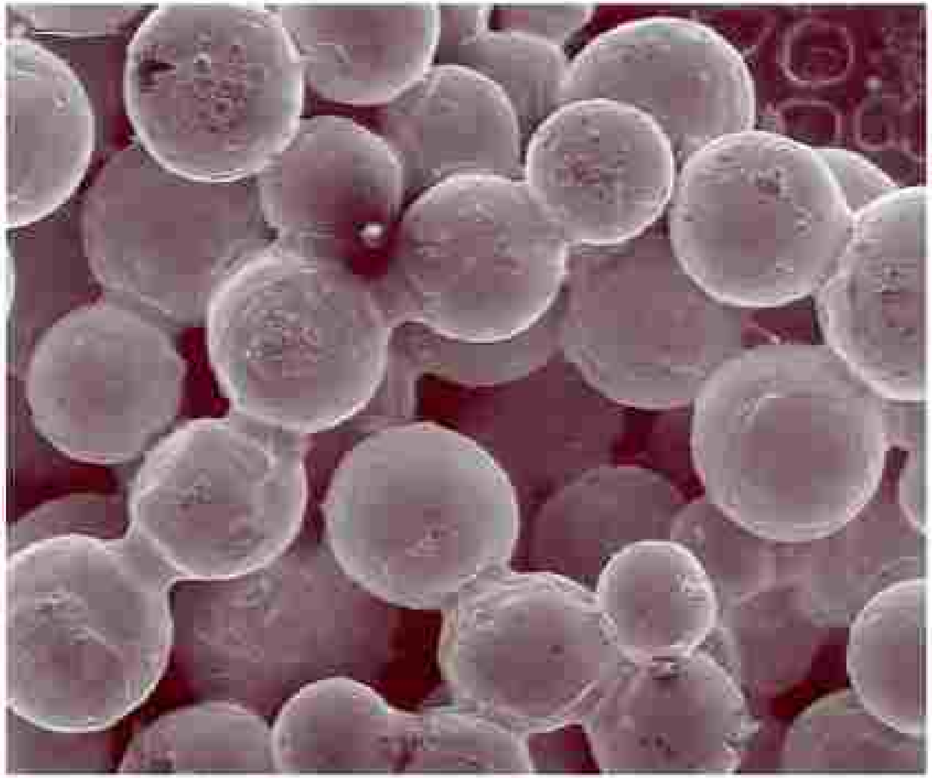


Figure 1.1 Scanning electron micrograph of bronze sphere sintering.

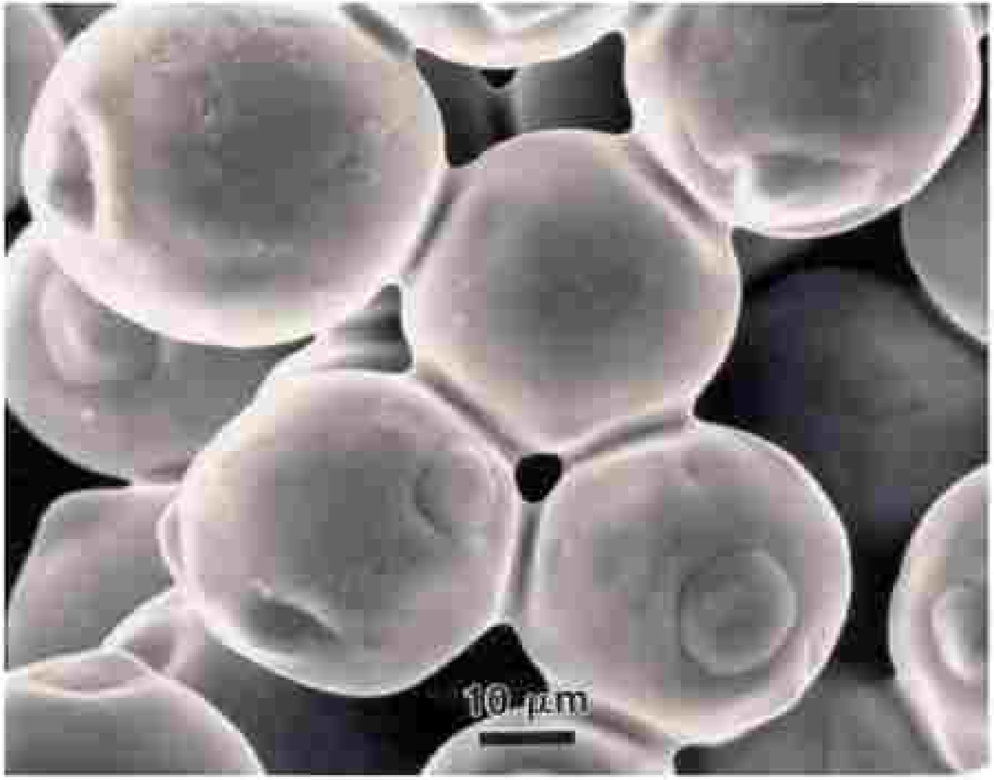
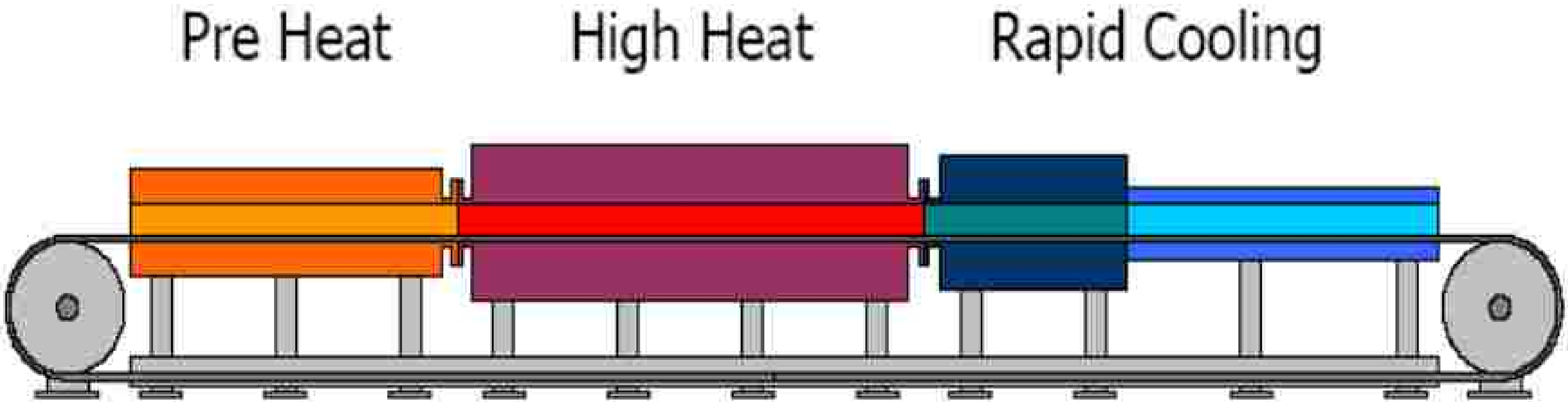


Figure 4.1 Scanning electron micrograph of neck growth between 32 µm nickel spheres during sintering at 1050°C (1323 K) for 30 min in a vacuum. Prior to sintering the particles were loosely packed into a crucible.

Sintering: From Empirical Observations to Scientific Principles
DOI: http://dx.doi.org/10.1016/B978-0-12-401682-8.00004-5

Sintering Furnace Zones



Continuous Furnace Temperature Profile

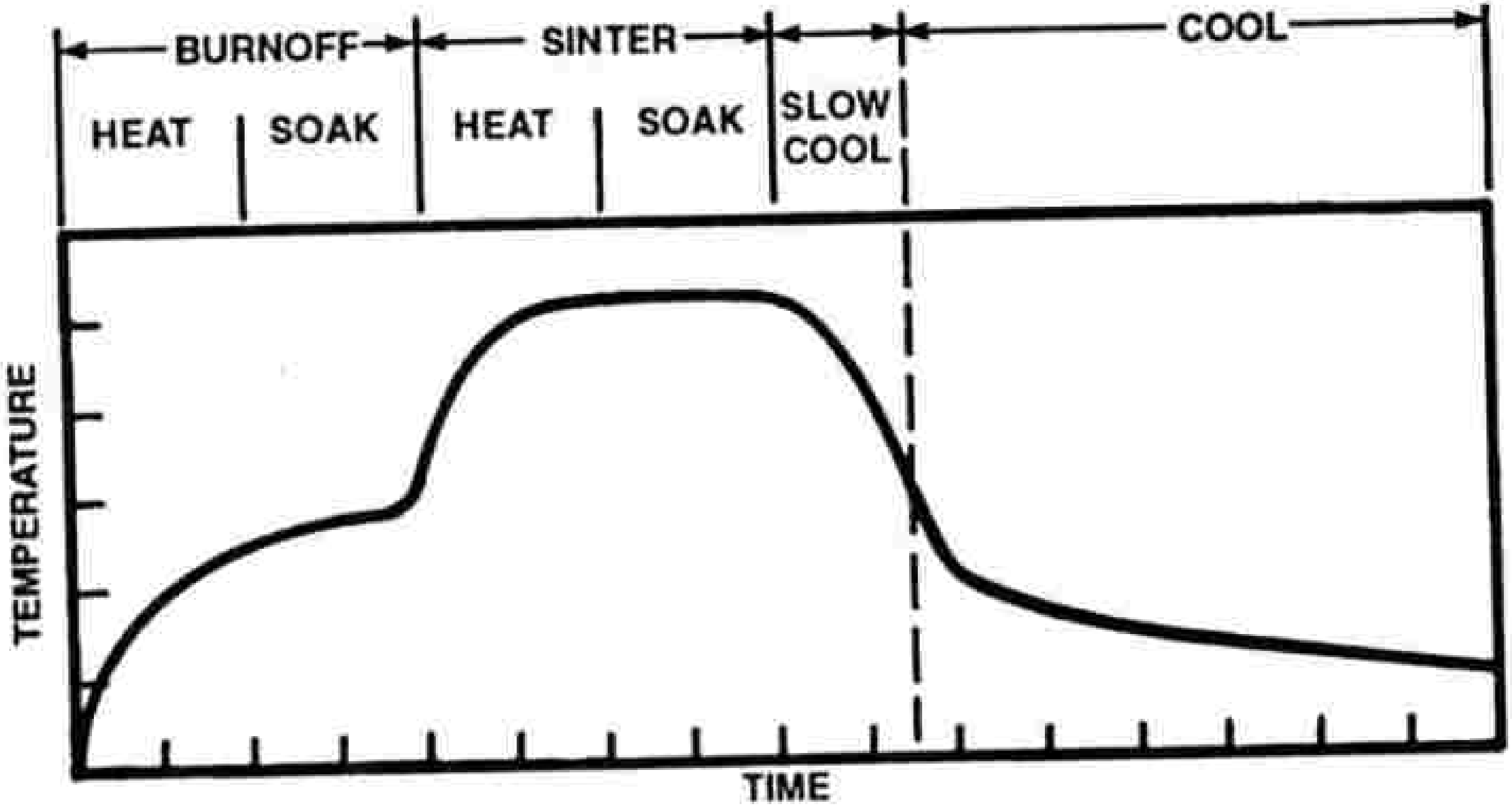
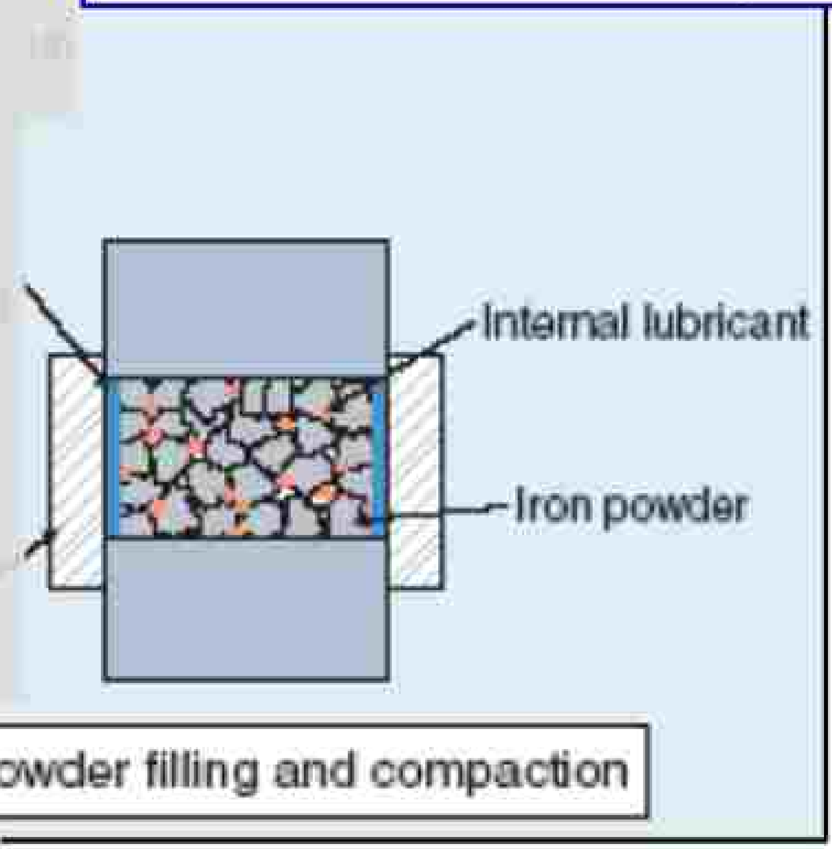


FIG. 11.18 Temperature profile for continuous-flow furnace. (From Ref. 9.)

There are two lubrication techniques.



One method is to blend a dry lubricant with the powdered metal.

With the powder lubrication method, the level of lubricant addition may range from 0.5 to 1.5%.

Characteristics of Sintering Furnaces

Design for Powder Metal Processing

TABLE 11.7 Typical Operating Temperatures for Sintering Furnaces

Furnace type	Maximum operating temperature (°C)
Continuous flow	
Belt	1150
Pusher	1150
Roller-hearth	1150
Walking beam	1650
Batch type	
Bell	2800
Elevator	2800
Vacuum	2800

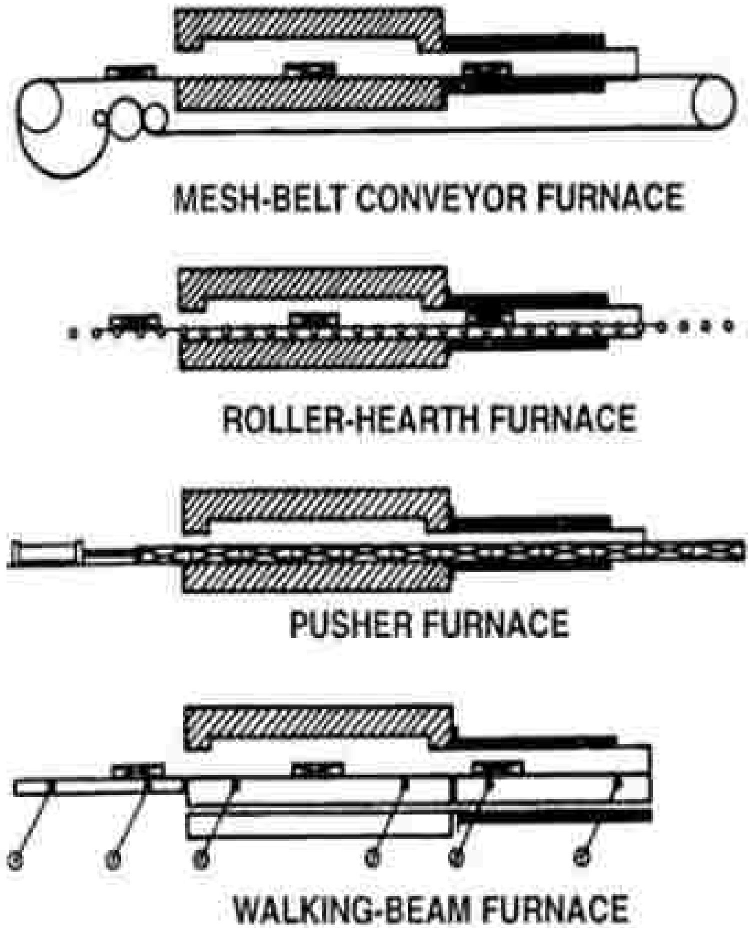


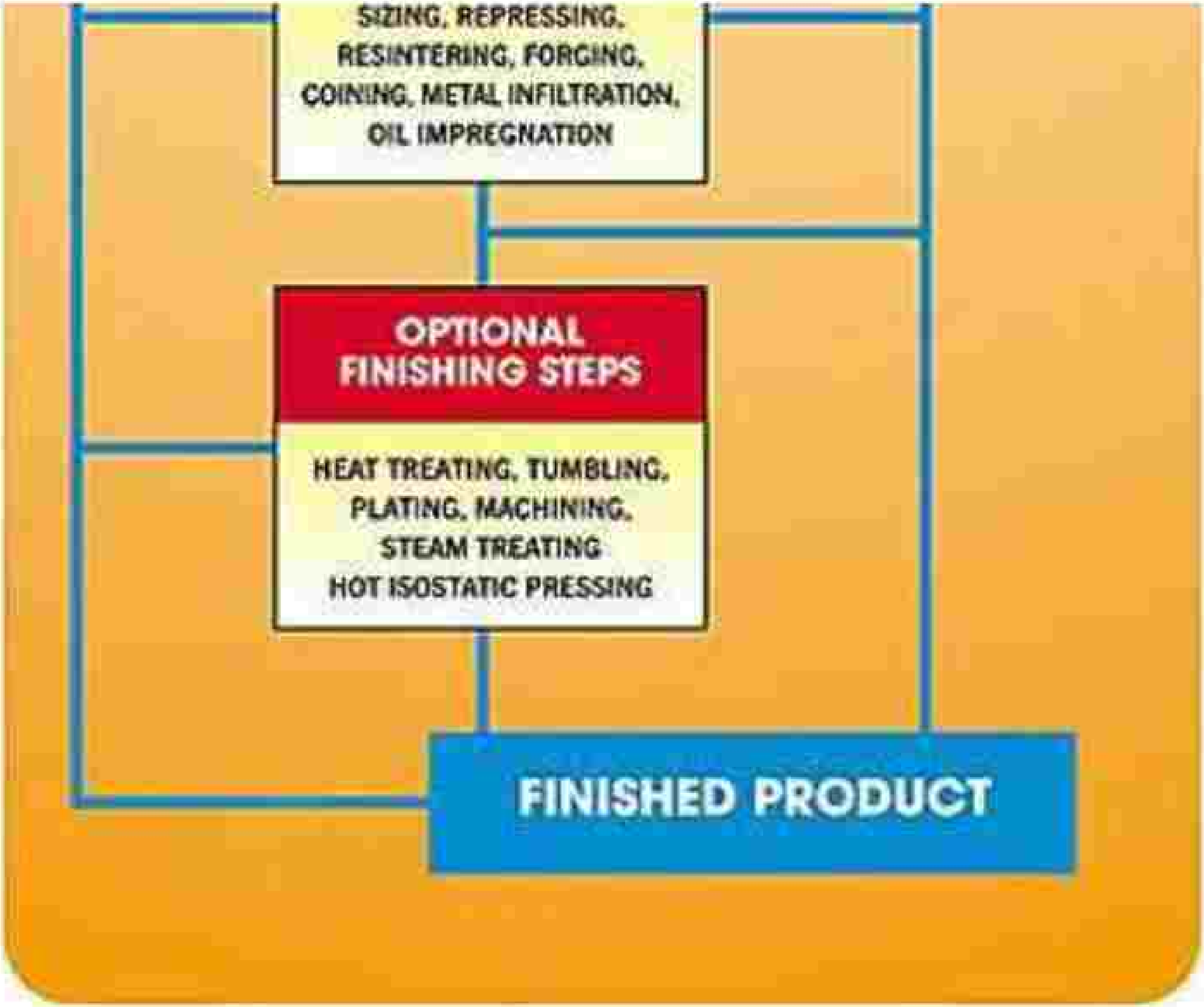
FIG. 11.17 Continuous-flow furnaces. (From Ref. 8.)

Sintering temperature required for different group of materials

Table 6-4: Sintering temperatures used for selected metallic and non-metallic materials (partly according to [6.4])

Material		Sintering temperature °C
Aluminium alloys		590 ... 620
Copper		600 ... 900
Bronzes		740 ...780
Brass		890 ... 910
Nickel		1000 ... 1150
Iron-carbon, iron-copper carbon		1120
Iron-copper-nickel carbon		1120
Iron-manganese copper		1120
Iron-copper-nickel molybdenum (Distaloy)		1120 ... 1200
Iron, iron-copper, iron-copper nickel		1120 ... 1280
Iron-chromium, iron-chromium copper		1200 ... 1280
Iron-manganese		1280
Iron chromium carbide (Cr_3C_2)	>	1280
Iron-vanadium carbide	>	1280
Iron-tungsten carbide	>	1280
Iron-manganese-vanadium-molybdenum- carbon	>	1280
Iron-manganese-chromium-molybdenum- carbon	>	1280
Electrolytic iron, carbonyl -iron, aluminium-nickel iron (soft and hard magnets)		1200 ... 1300
Hardmetals		1200 ... 1400
Heavy metals (heavy metals of W)		1300 ... 1600
Tungsten alloys		1400 ... 1500
Nitrides		1400 ... 2000
Molybdenum disilicide ($MoSi_2$ heating elements)		to 1700
Aluminium oxide (Al_2O_3 - ceramic cutting tools)		*1800 - 1900*
Tungsten, molybdenum, tantalum		2000 ... 2900

Ref. ASM


SIZING, REPRESSING, RESINTERING, FORGING, COINING, METAL INFILTRATION, OIL IMPREGNATION
OPTIONAL FINISHING STEPS
HEAT TREATING, TUMBLING, PLATING, MACHINING, STEAM TREATING HOT ISOSTATIC PRESSING
FINISHED PRODUCT

Secondary operations are performed to increase density, improve accuracy, or accomplish additional shaping of the sintered part

- *Repressing* - pressing the sintered part in a closed die to increase density and improve properties
- *Sizing* - pressing a sintered part to improve dimensional accuracy
- *Coining* - pressworking operation on a sintered part to press details into its surface
- *Machining* - creates geometric features that cannot be achieved by pressing, such as threads, side holes, and other details

Effect of *double compacting* on mechanical properties of *Cr-Mo prealloyed PM steels*

Maziyar AZADBEH

2007 2008 2011

Materials Engineering Faculty
Sahand University of Technology

AS-REPRESSED PROPERTIES OF DOUBLE COMPACTED Cr-Mo AND Mo PREALLOYED PM STEELS

M. Azadbeh, H. Danninger, Ch. Gierl

Abstract
Obtaining higher densities is a major target in powder metallurgy, and there are many parts that require higher densities than can be obtained by conventional die compaction. One method for solving this problem is double compaction, which seems to be a potentially attractive production route in PM also for Cr-Mo and Mo alloyed steels. The objective of this research was to find the optimum conditions for obtaining higher densities and minimise interconnected porosity. The effect of the temperature of intermediate annealing was studied for Cr-Mo and Mo prealloyed steels, respectively, and the optimum temperature range was identified. It could be observed that the density of repressed samples increases with higher annealing temperature up to a certain limit, softening of the matrix as well as generation of free porosity through some C dissolution being helpful. On the other hand, too high annealing temperatures should be avoided either, since too much dissolution of carbon during annealing is detrimental, resulting in harder and less deformable compacts. Even at this latter condition, however, no repressing cracks were observed.
Keywords: sintered steels, double pressing, density, annealing

STUDY ON THE INTERPARTICLE BONDING OF DOUBLE PRESSED PM ALLOY STEELS

M. Azadbeh, H. Danninger, Ch. Gierl

Abstract

Double pressing is a common technique for improving the relative density of sintered steel components, with resulting beneficial effect on the mechanical properties. To eliminate the work hardening introduced by the first pressing, an intermediate anneal is done before the second pressing, typically at temperatures at which carbon is not yet dissolved. In this work, interparticle bonding caused by the intermediate anneal is described through fractographic techniques for prealloyed steels Fe-Mo-C and Fe-Cr-Mo-C and compared to the fracture surfaces after final sintering. It showed that after annealing, interparticle bonding is significantly more pronounced in the Mo alloyed steel than in the Cr-Mo grade, apparently as a consequence of the more stable surface oxides in the latter material. After final sintering however there are virtually no differences and with regard to mechanical properties the Cr-Mo material offers considerable advantages.

Keywords: sintered steels, double pressing, presintering, interparticle bonding

International Journal of ISSI, Vol.7 (2010), No.2, pp.1-5

Investigation of influences of alloying elements and sintering temperature on the properties of high strength low alloyed sintered steel

M. Azadbeh[1], N. Peyghambardoust[2], VM. Mohammadpour[3]* and A. Kalantari[4]
Department of Materials Engineering, Sahand University of Technology, Tabriz, Iran, P.O.Box 51335-1996

Abstract

Producing parts with high density and improved mechanical properties is one of the most important aims of powder metallurgy process. There are many factors for attaining modified properties in sintered parts but among them controlling type and quantity of alloying elements and manufacturing parameters such as compacting pressure, sintering temperature are the most effective.

In this research, two series of Cr-Mo prealloyed powders with 1.5% and 3% chromium contents were used, and then influences of manufacturing parameters on physical and mechanical properties were investigated. The results show that by compacting pressure and sintering temperature increment and chromium content decrement, density is increased and subsequently physical and mechanical properties of low alloyed sintered steels are improved.

Keywords: Low alloyed sintered steel, sintering temperature, density, electrical-conductivity, mechanical properties.

Available online at www.sciencedirect.com

ScienceDirect

JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2011, 18(2): 52-56

Effect of Intermediate Annealing Temperature on Response of Repressing to Densification of Pre-Alloyed Cr-Mo Steel

Amir Kalantari, Maziyar Azadbeh

(Department of Materials Engineering, Sahand University of Technology, Tabriz 53317-11111, Iran)

Abstract: Increasing density is one of the important factors for producing high quality powder metallurgy (PM) parts, which has beneficial effect on mechanical properties. One of the common techniques for achieving this goal is double compacting, which seems to be a potentially attractive method in PM route, also for Cr-Mo alloyed-steels. The objective of this research was to investigate the effect of first compacting pressure and intermediate annealing temperature on attaining higher densities and minimum interconnected porosity for Cr-Mo pre-alloyed steel. The effect of mentioned parameters was studied by measuring density, transverse rupture strength and macrohardness of repressed samples. The results show that for each first compacting pressure, the density range of repressed samples increases with the increasing annealing temperature up to a certain limit, due to C dissolution which causes free porosity and further densification. Annealing temperatures higher than optimum one should be avoided, since too much carbon dissolution results in harder and less deformable compacts. On the other hand, with regard to repressed density and other resulted properties, the amount of first compacting pressure offers considerable advantage in obtaining higher level of density and consequently improved mechanical properties.

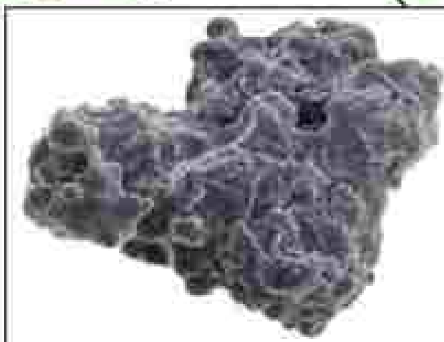
Key words: double compacting; repressed density; repressed transverse rupture strength; intermediate annealing temperature

Material:

Fe-Cr-Mo-C (Fe - 1.5% Cr – 0.2% Mo)+ 0.6% C

Properties of **Fe-Cr-Mo** powder	
Apparent density	2.85 g/cm³
Flow	26 sec/50g
Particle size	45-150 μm
Chemical analysis, %	
C	<0.01
Chromium	1.50
Molybdenum	0.20

Fe-Mo-C (Fe - 1.5% Mo)+ 0.6% C



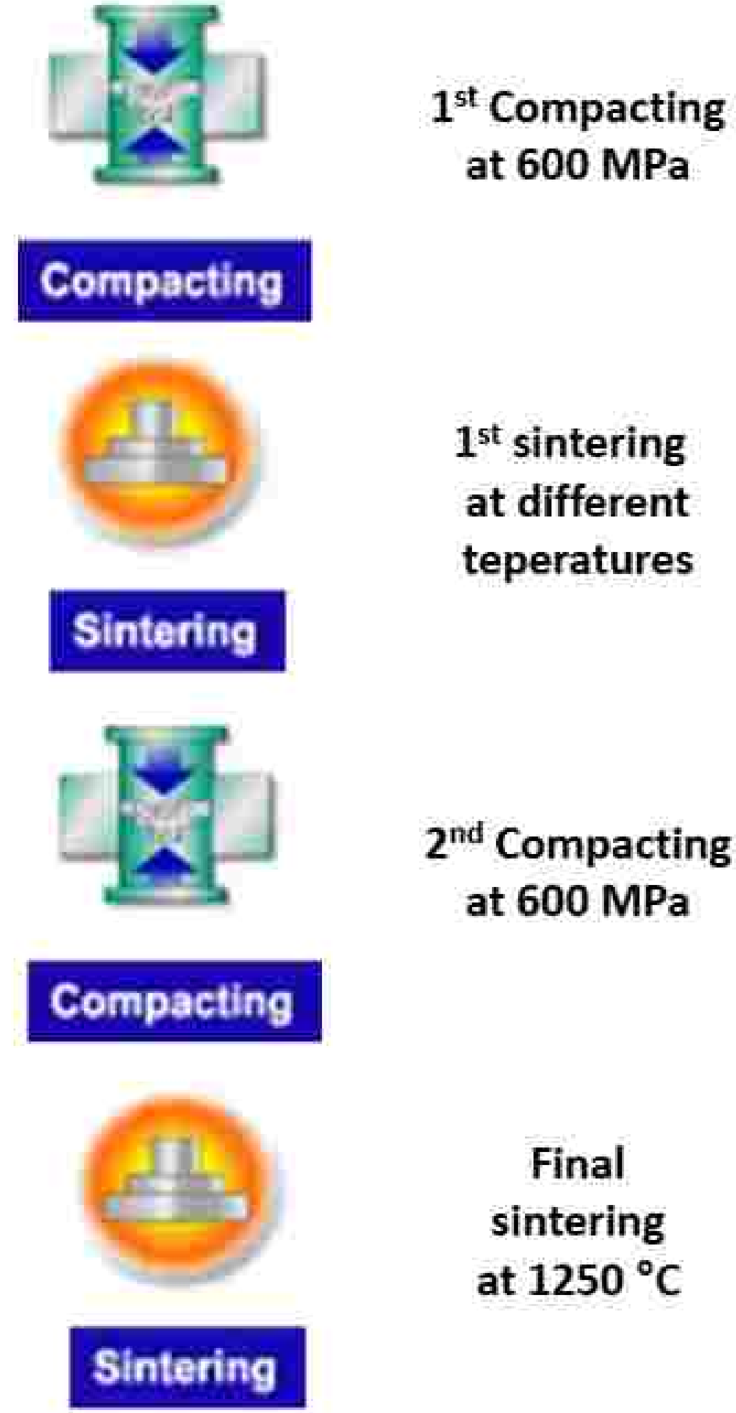
Properties of **Fe-Mo** powder	
Apparent density	3.1 g/cm³
Flow	25 sec/50g
Particle size	45-150 μm
Chemical analysis, %	
C	<0.01
Molybdenum	1.50

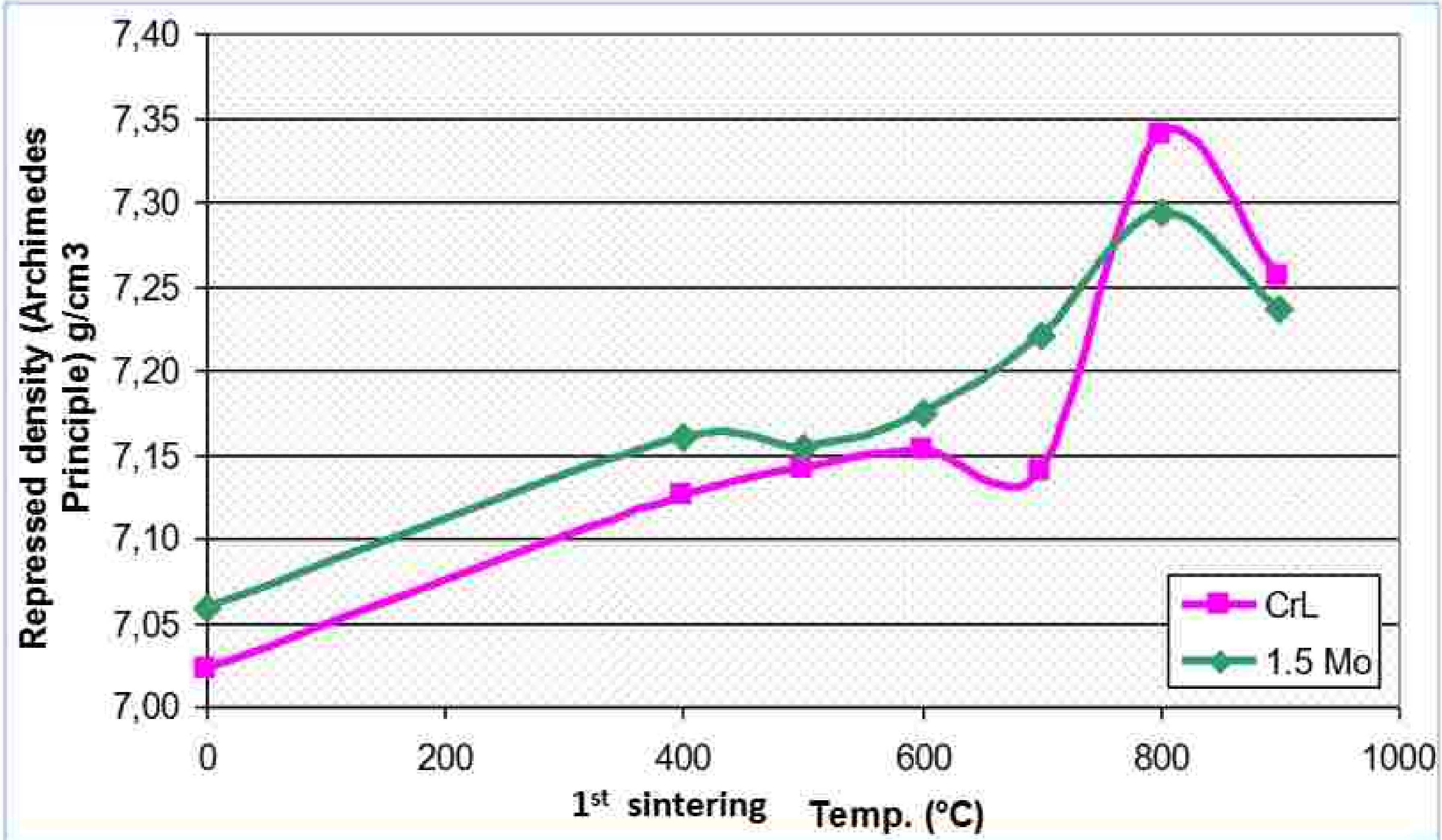
Specimen:

Rectangular bars: 55 mm x 10 mm x 10 mm

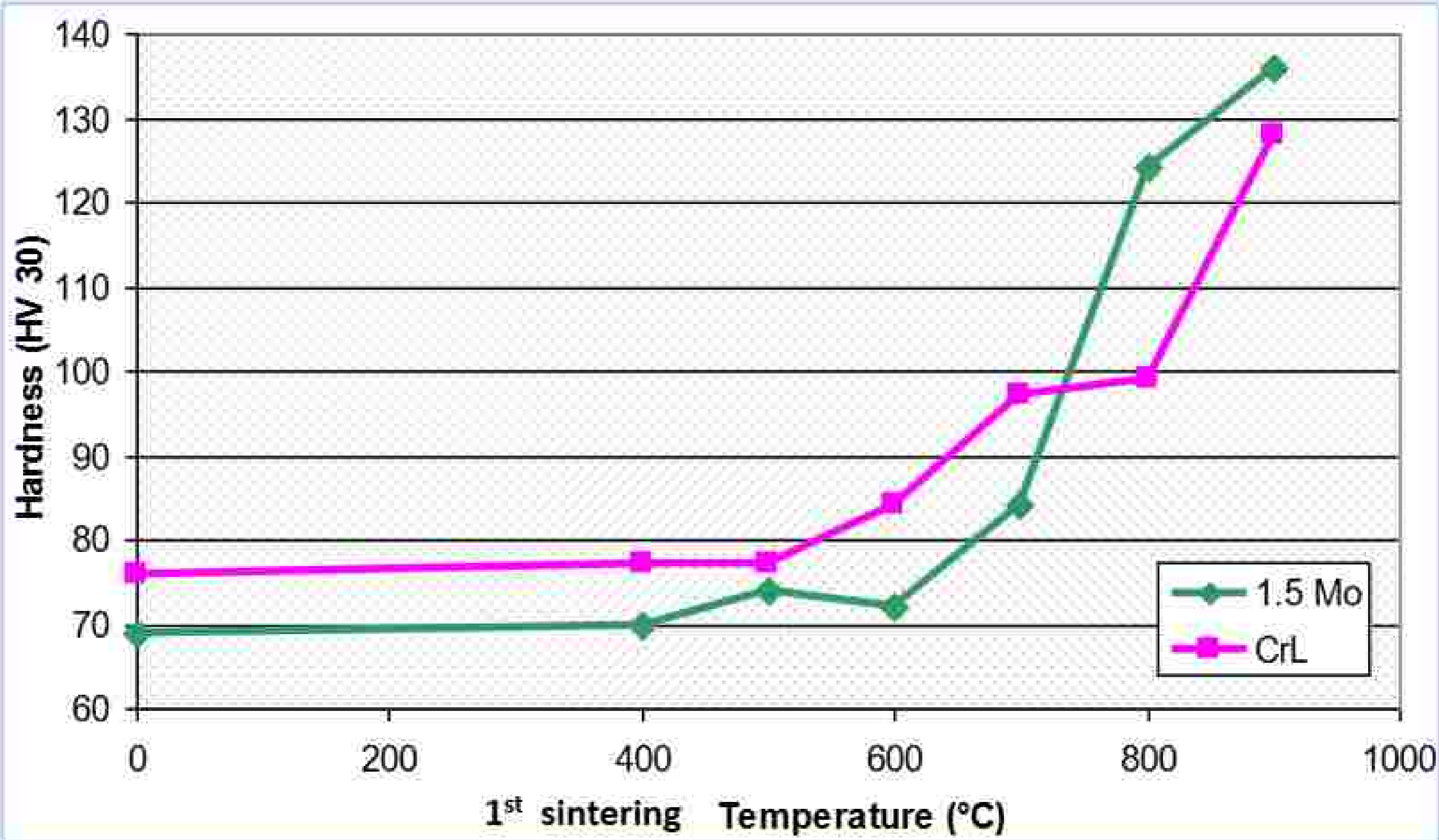
Sintering:

Sintering at 1250°C was carried out in a laboratory furnace with gas tight superalloy retort in **flowing high purity nitrogen** (min. 99.999 purity, flow rate 2 l/min).

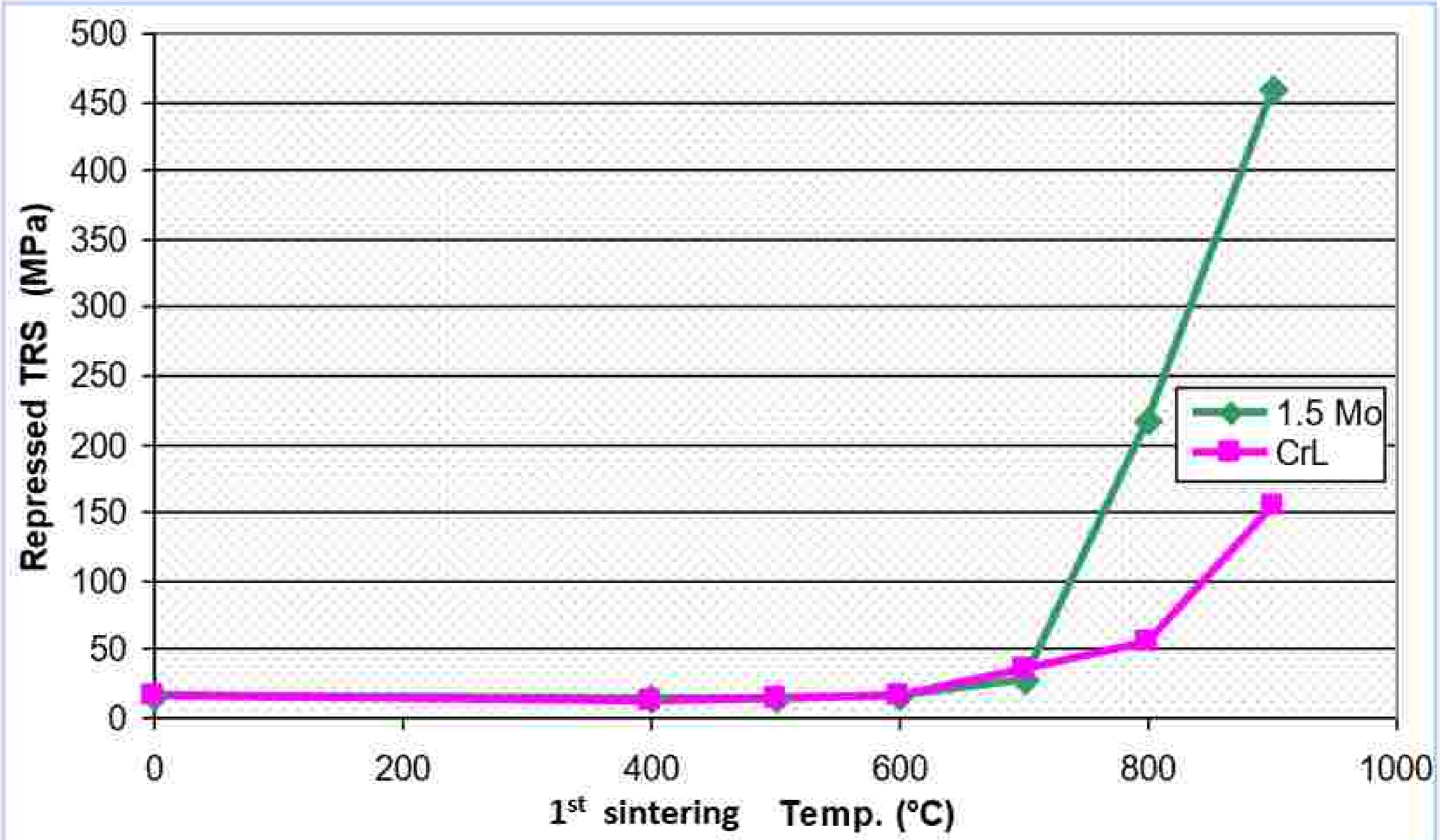




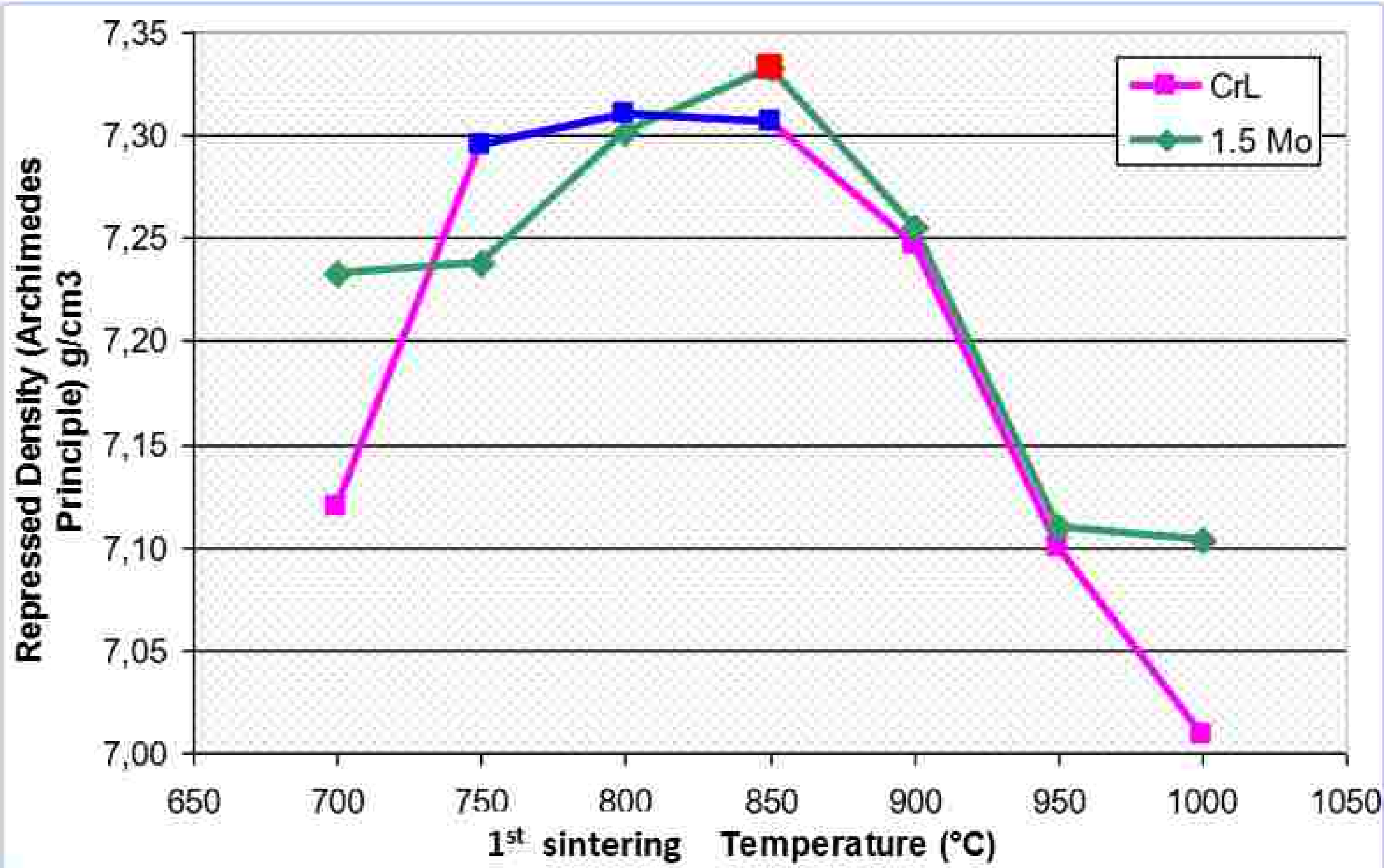
Effect of 1st sintering on repressed density (obtained by Archimedes principle). 600 + 600 MPa, intermediate anneal 30 min in N_2



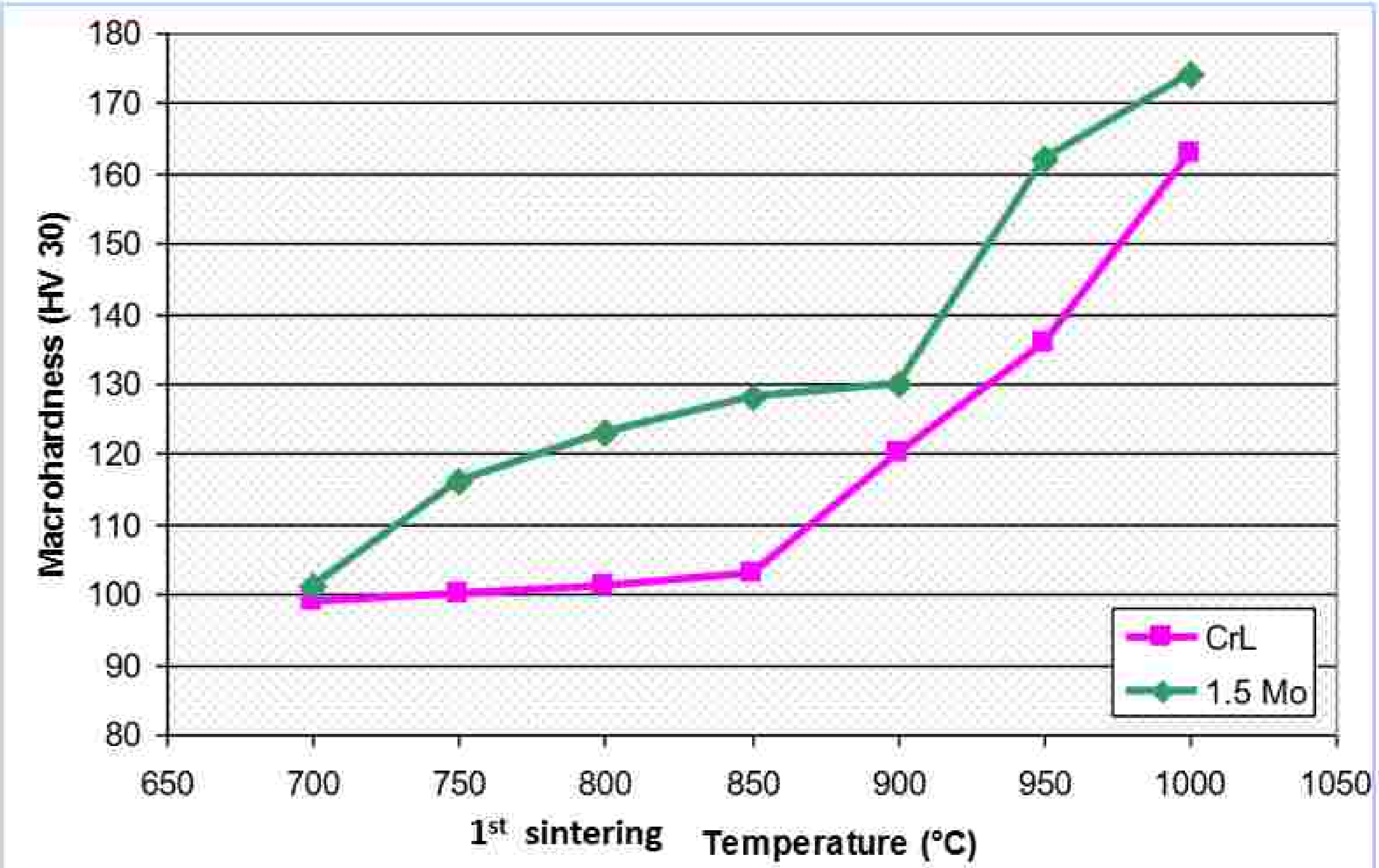
Effect of intermediate sintering on macrohardness of repressed Fe-Cr-Mo-C and Fe-Mo-C.



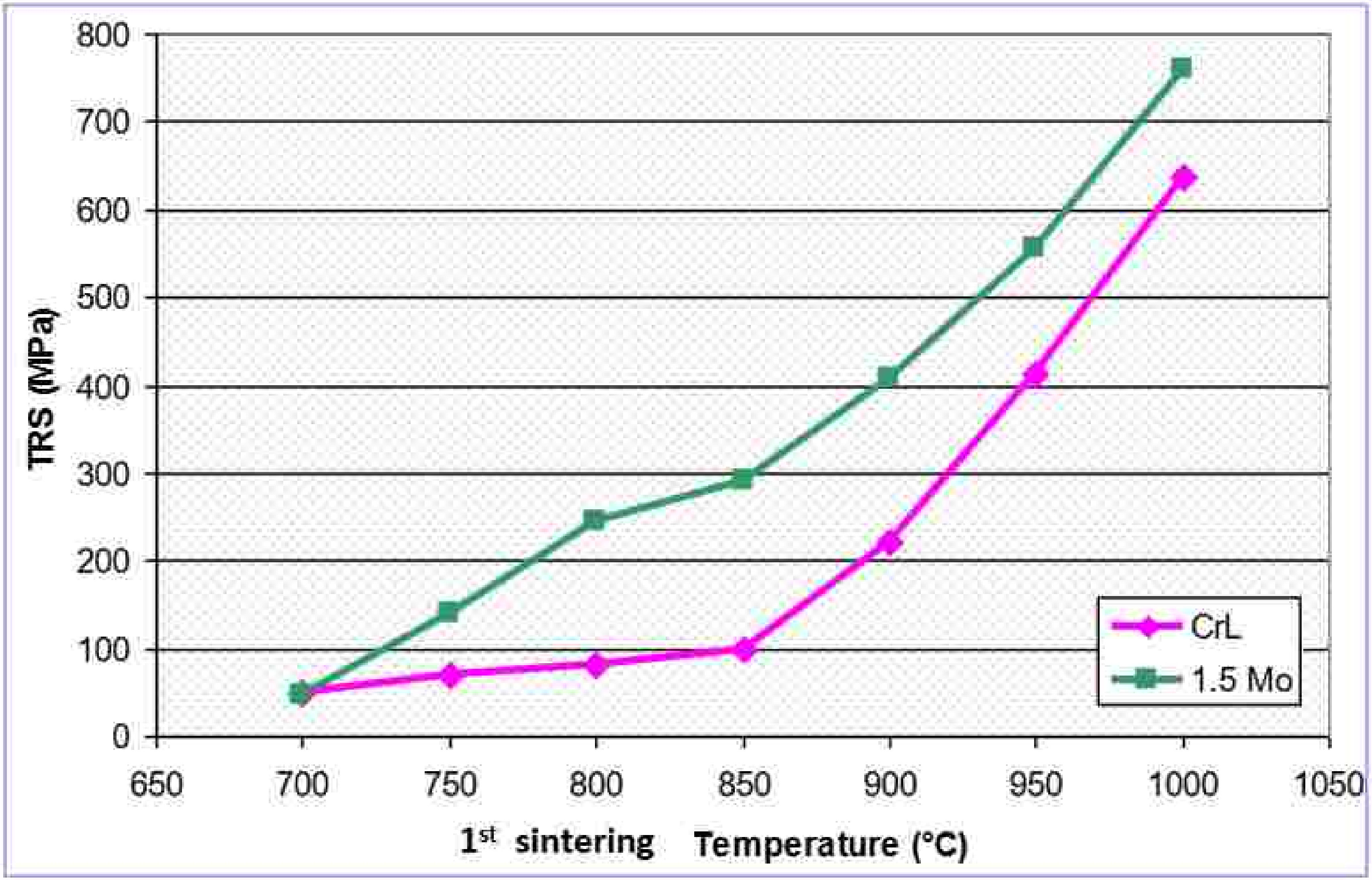
Effect of the intermediate sintering temperature on transverse rupture strength of repressed Fe-Cr-Mo-C and Fe-Mo-C



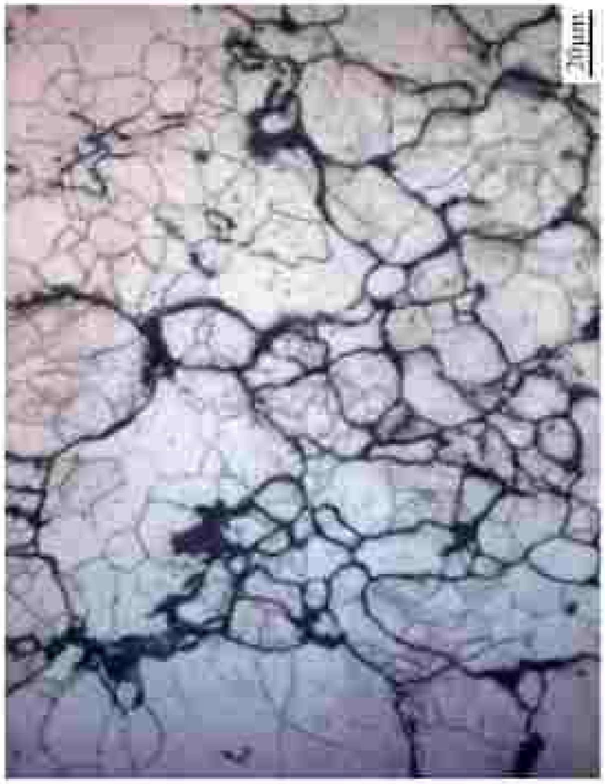
Effect of 1st sintering temperature on repressed density
(obtained by Archimedes principle) after repressing at 600MPa.



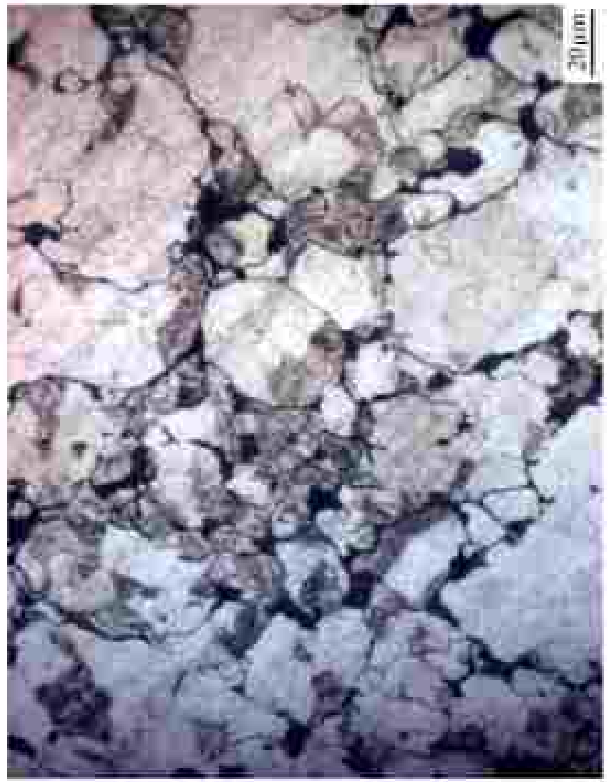
Effect of 1st sintering temperature on macrohardness of repressed samples



Effect of 1st sintering temperature on repressed transverse rupture strength of samples



At 700 °C



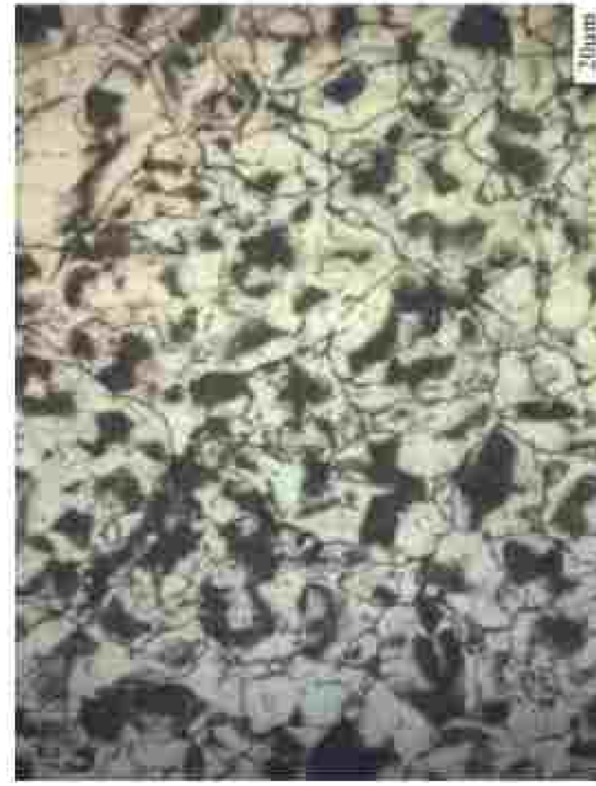
At 800 °C

At 900 °C

Microstructure of **Fe-Mo-C**,
compacted at **600 MPa** and
1st sintered at the indicated temperature for 30 min, and
repressed at **600 MPa**. (As repressed)

At 700 °C

At 800 °C



At 900 °C

Microstructure of **Fe-Cr-Mo-C**,
compacted at **600 MPa** and
1st sintered at the indicated temperature for 30 min, and
repressed at **600 MPa**. (As repressed)

Green – 1st sintered at 1000°C

Repressed

Fe-Mo-C

Green – 1st sintered at 1000°C

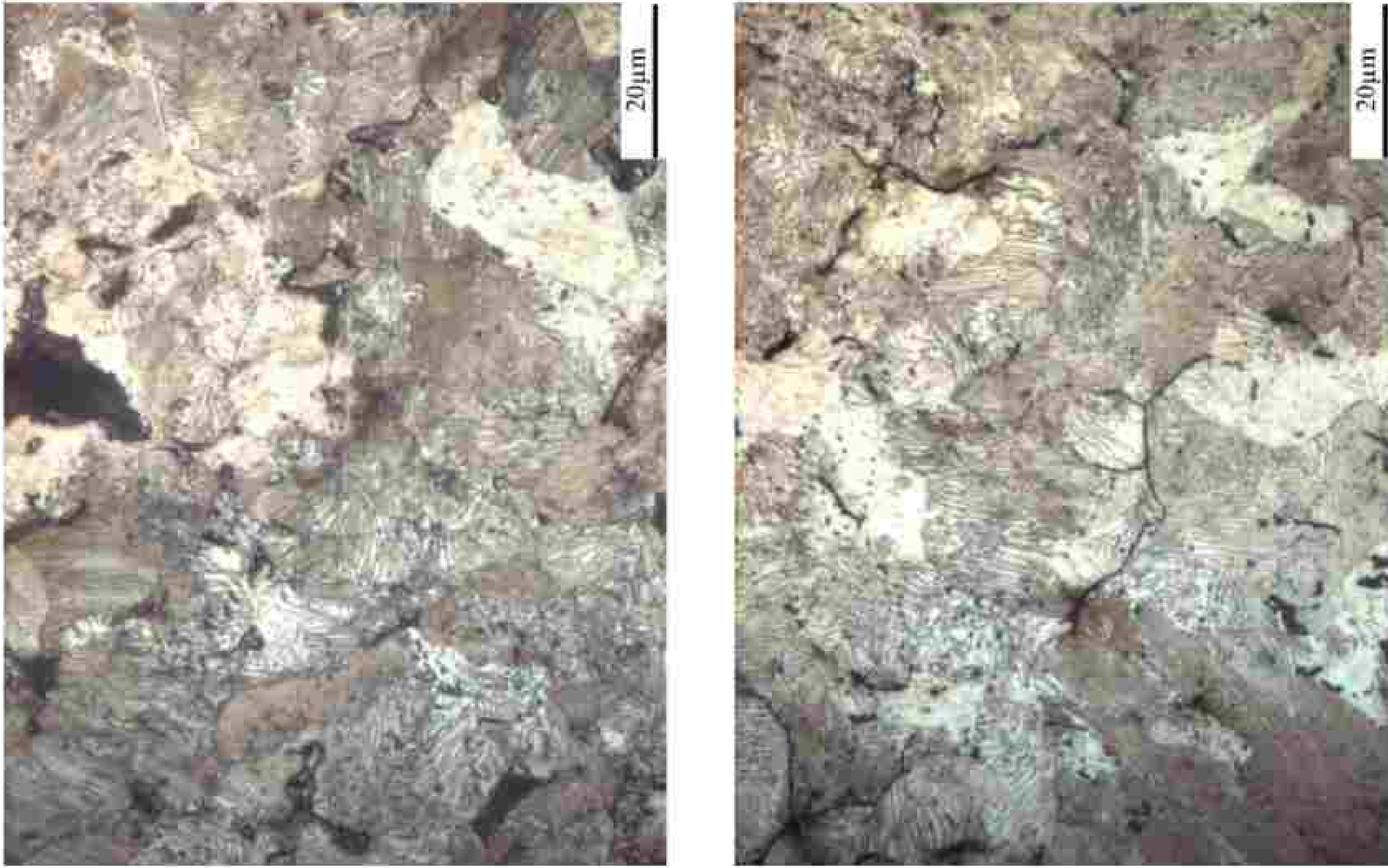
Repressed

Fe-Mo-C

Green – 1st sintered at 1000°C

Repressed

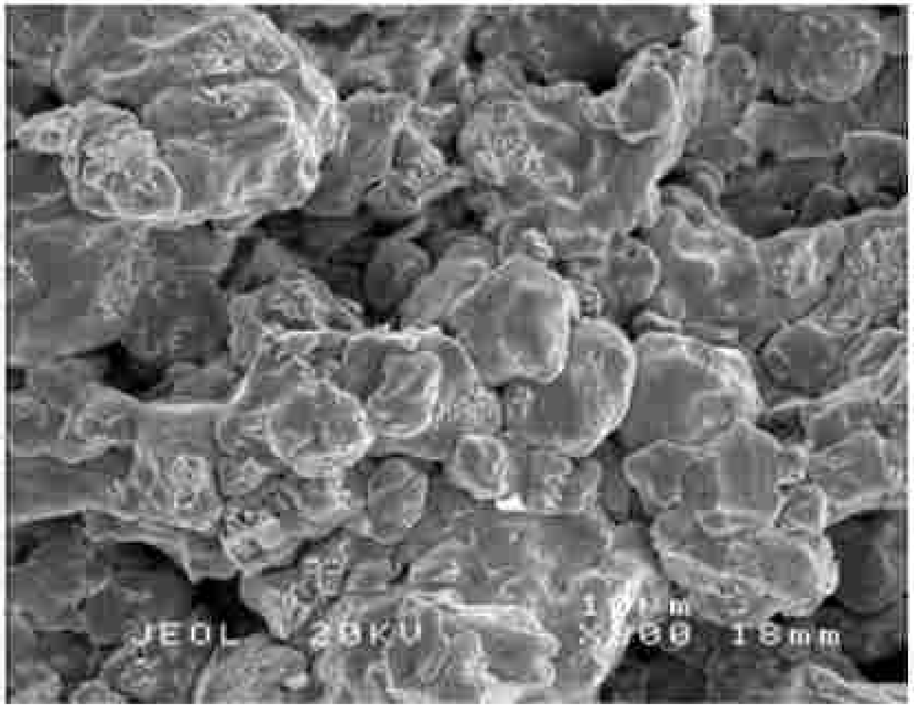
Fe-Cr-Mo-C



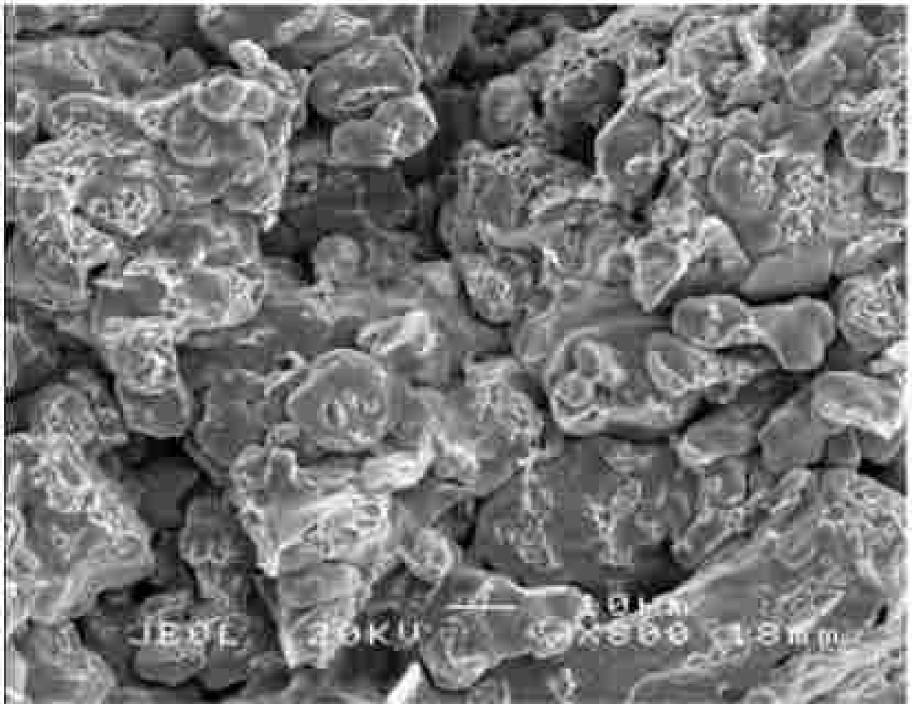
Green – 1st sintered at 1000°C

Repressed

Fe-Cr-Mo-C

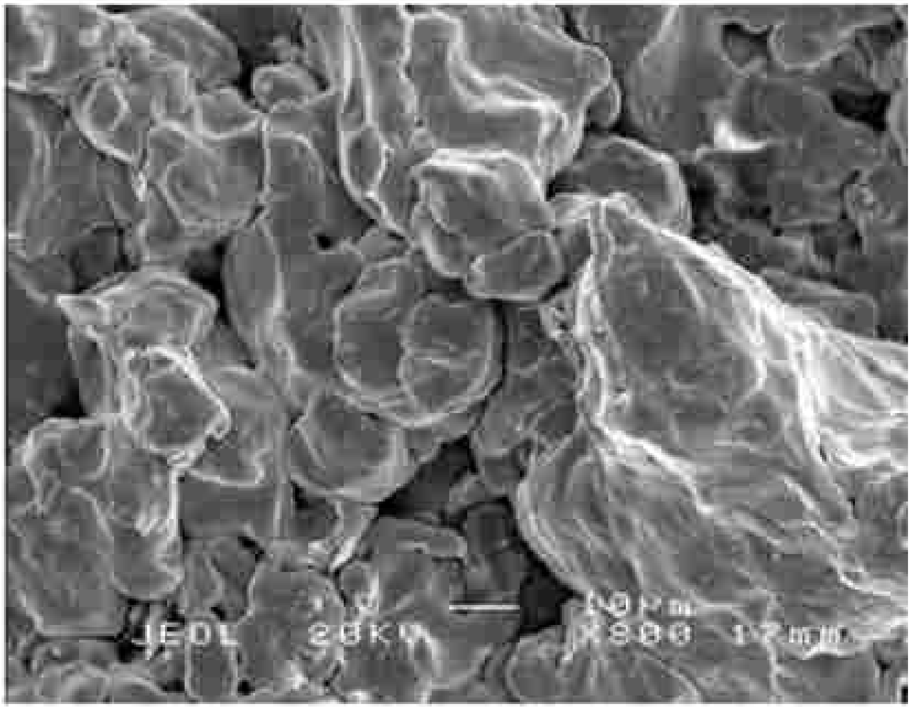


At 800 °C

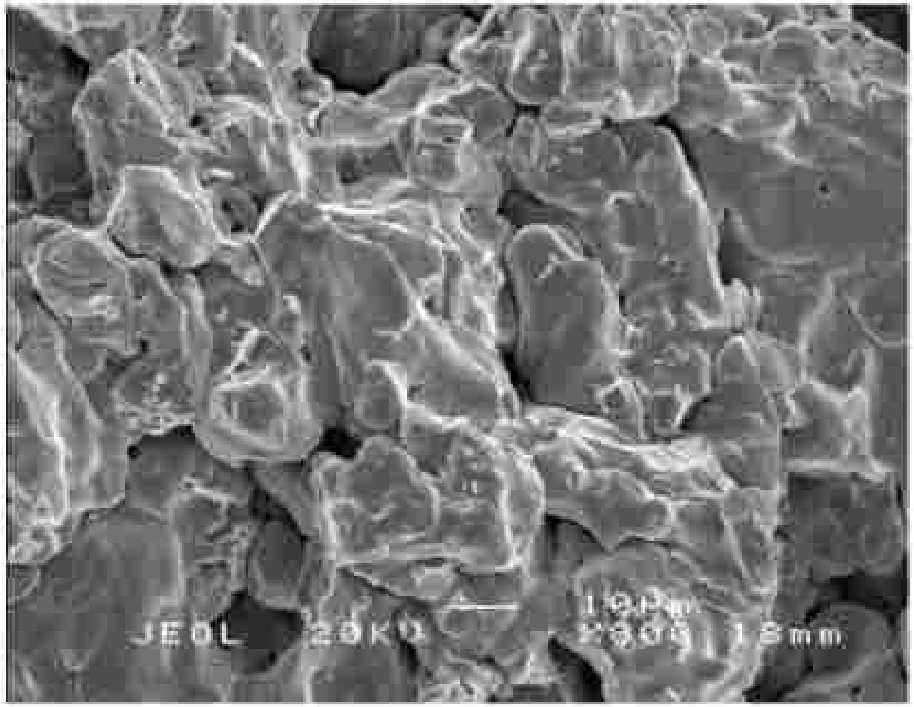


At 900 °C

Fracture surface of repressed **Fe-Mo-C**,
compacted at **600 MPa** and
1st sintered at the indicated temperature for 30 min, and
repressed at **600 MPa**. (As repressed)



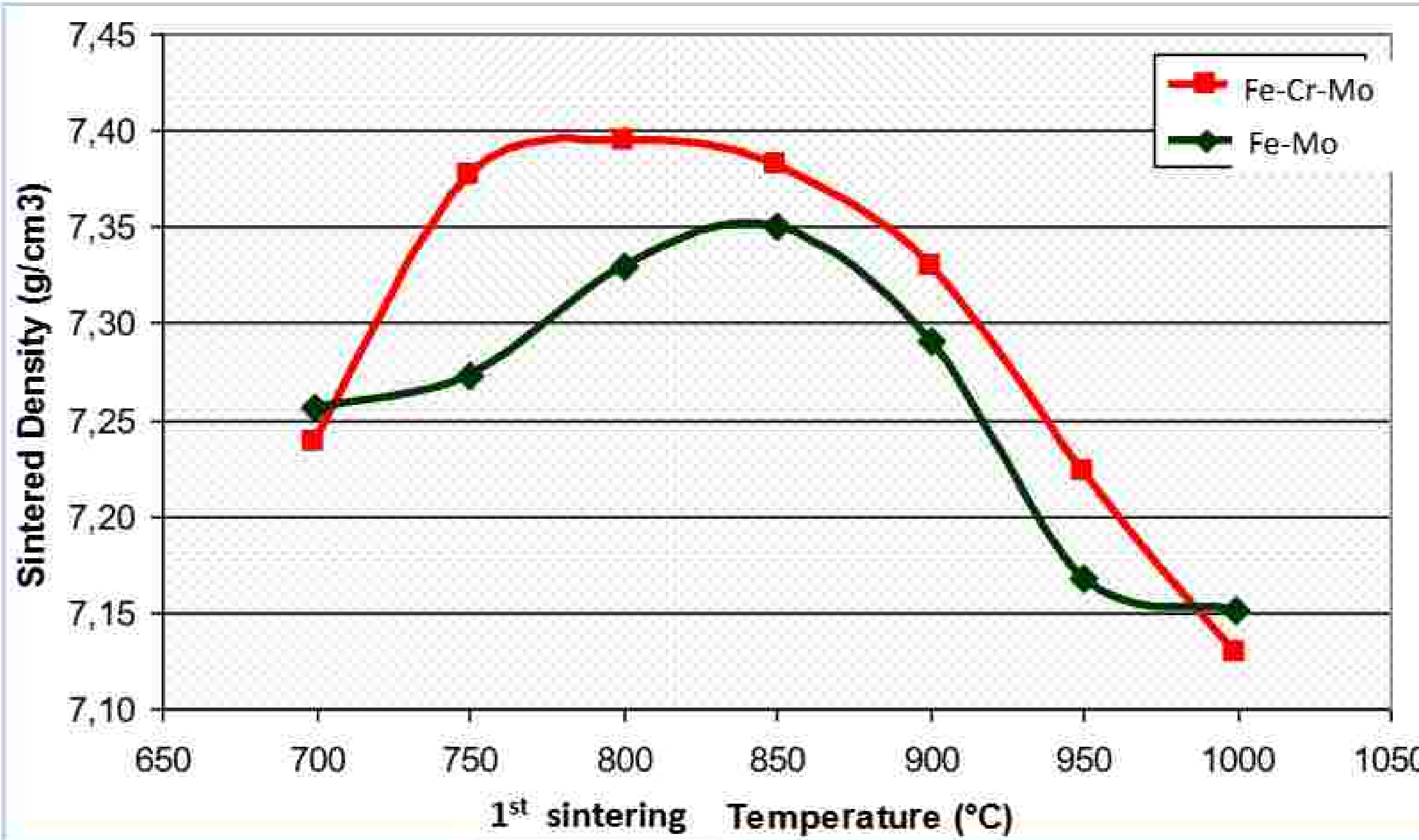
At 800 °C



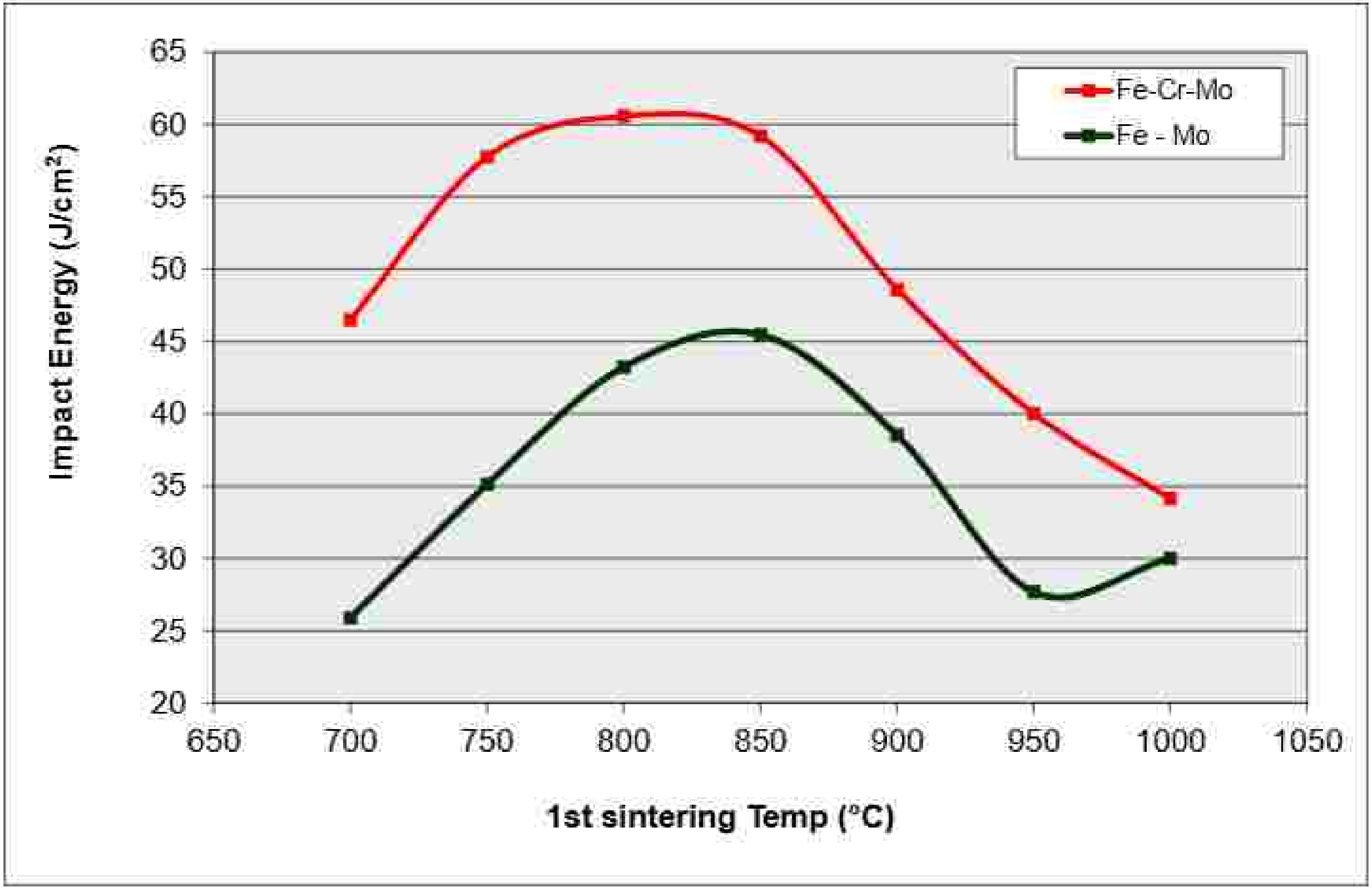
At 900 °C

Fracture surface of repressed **Fe-Cr-Mo-C**,
compacted at **600 MPa** and
1st sintered at the indicated temperature for 30 min, and
repressed at **600 MPa**. (As repressed)

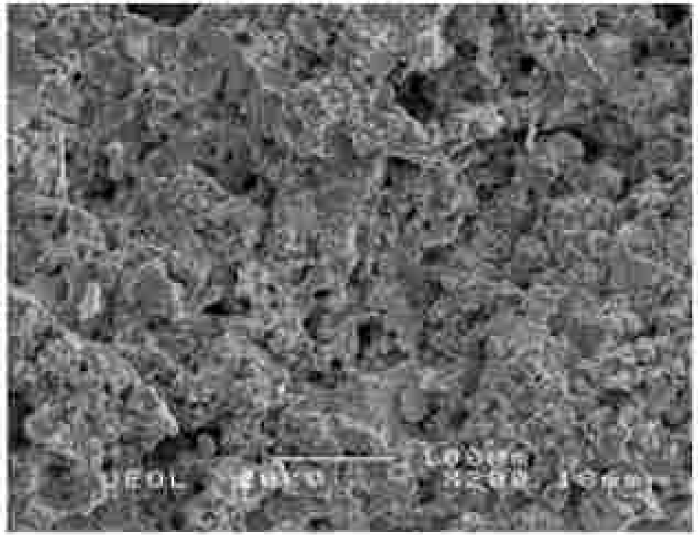
Effect of intermediate sintering temperature on sintered density



Effect of intermediate sintering temperature on impact energy



Fracture surface of repressed and then **sintered Fe-Mo-C** as a function of 1st sintering tempareture



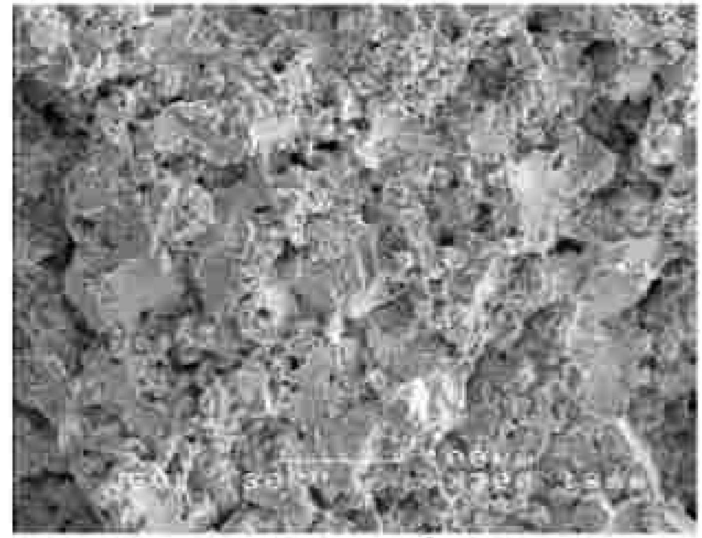
500 °C

Compacted 600 MPa,

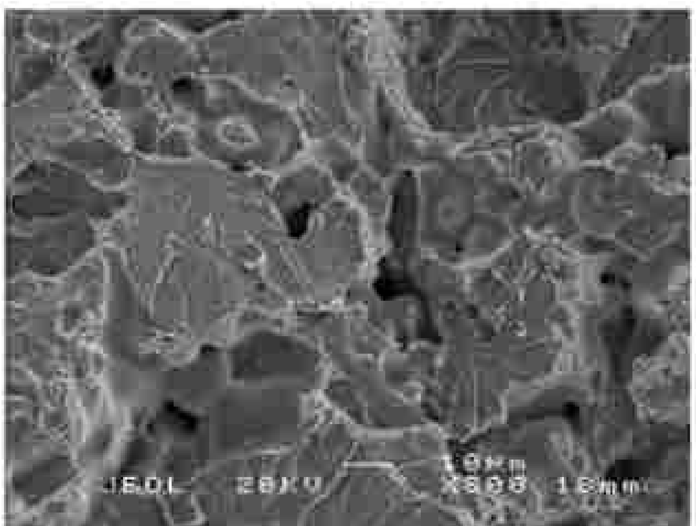
1st sintering - 30 min in N_2

Repressed at 600 MPa,

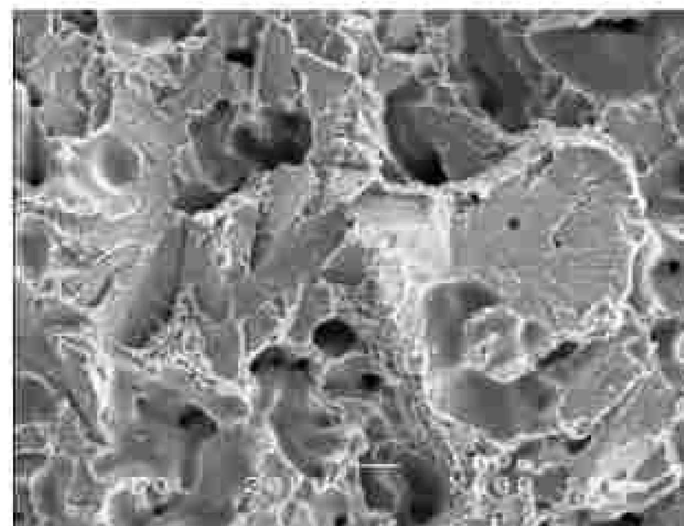
sintered- 60 min at 1250°C in N_2



800 °C



500 °C, higher magnification



800 °C, higher magnification

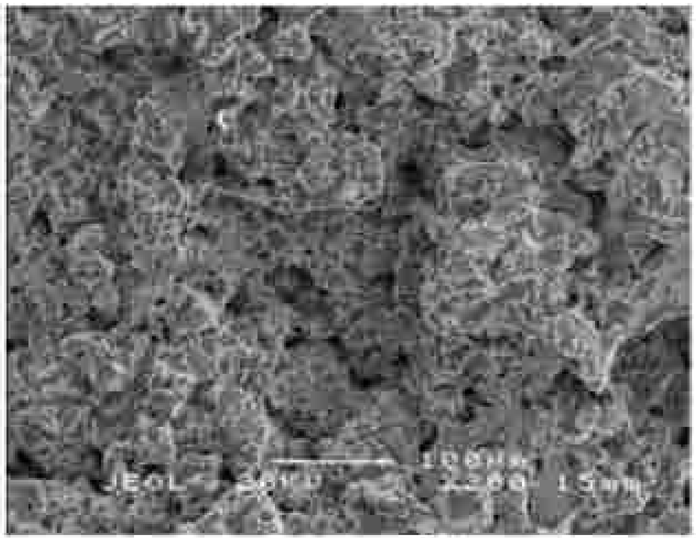
Fracture surface of repressed and then **sintered Fe-Cr-Mo-C** as a function of 1st sintering tempareture

Compacted 600 MPa,

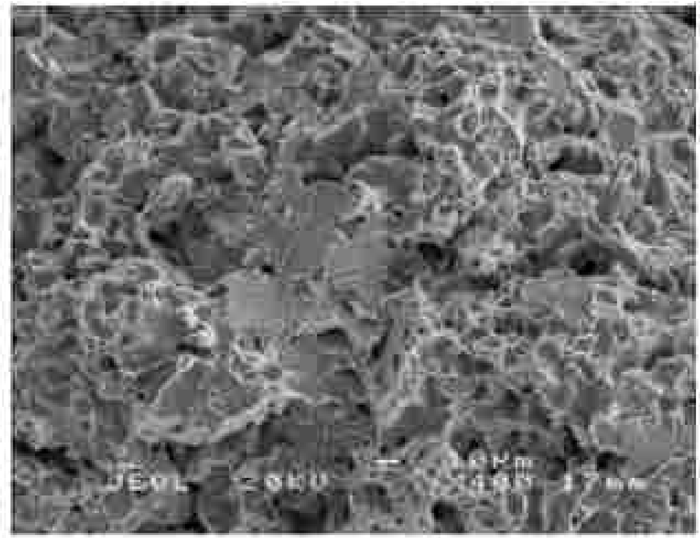
1st sintering - 30 min in N_2

Repressed at 600 MPa,

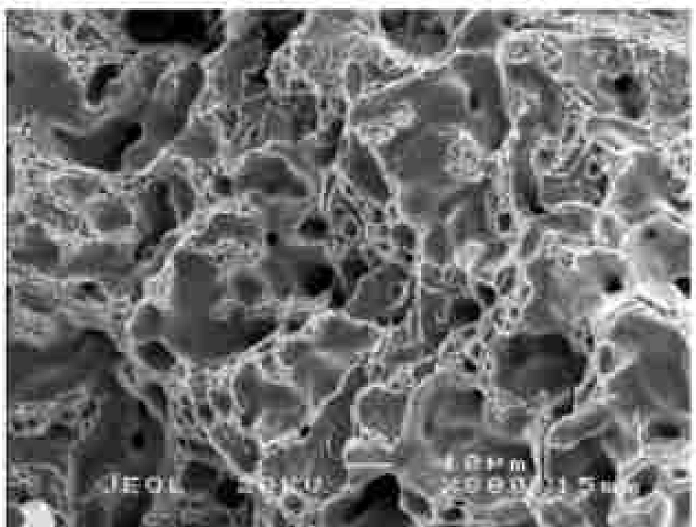
sintered- 60 min at 1250°C in N_2



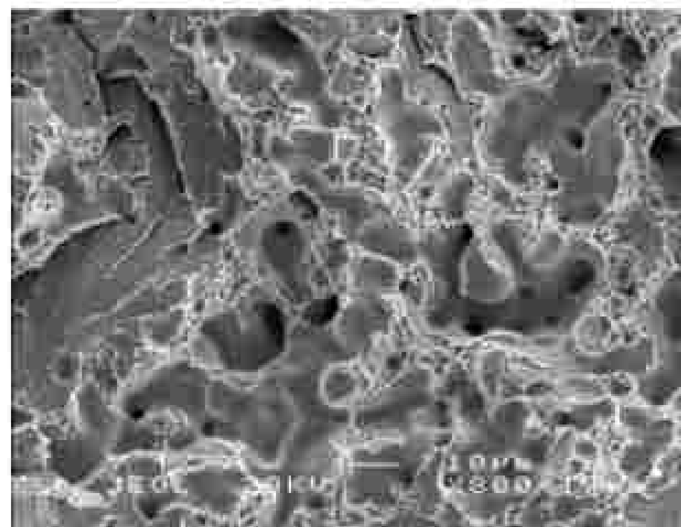
500 °C



800 °C



500 °C, higher magnification



800 °C, higher magnification

- PM alloys are true engineered materials, and in order to achieve the highest density, hardness and impact energy in PM steels, it is necessary to **optimise** the properties of both **interparticle and intraparticle regions**.
  - By proper manufacturing parameters, **higher sintered densities** such as 7.39 and 7.35 g/cm3, respectively for **Fe-Cr-Mo-C** and **Fe-Mo-C** using described method under double compacting at 600 MPa and sintering at 1250°C for 1 h in N_2 are achievable.
  - This technology offers opportunities for development of high performance PM materials.
- **Improved mechanical properties** are achieved by such a process, which **is a consequence of the increased sintered density**.

- This trend **can be improved with increasing annealing temperature** to the specific temperature around **800 - 850°C**.
  - **At higher examined annealing temperature** the **repressibility drops**.
    - Because the **microstructure** obtained after annealing at higher temperature is **comparable to very low temperature sintered bodies**, the macrohardness of green bodies before repressing increases and repressing will be done in harder samples since the repressing has to overcome the already built up **sintering necks**, that can cause defects and **microcracks**, which may be not healed during sintering process.
    - On the other hand annealing at higher temperature is **uneconomic**.

Sizing

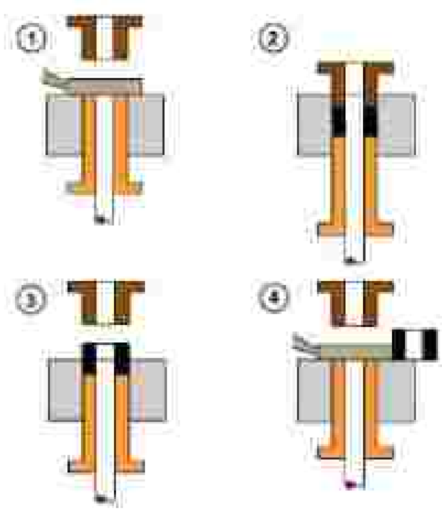
Secondary operations are performed to increase density, improve accuracy, or accomplish additional shaping of the sintered part

- *Repressing* - pressing the sintered part in a closed die to increase density and improve properties
- *Sizing* - pressing a sintered part to improve dimensional accuracy
- *Coining* - pressworking operation on a sintered part to press details into its surface
- *Machining* - creates geometric features that cannot be achieved by pressing, such as threads, side holes, and other details

Sizing: بطور نوعی امکانپذیر است که قطعات زینتر شده با دقتی که دارای تلرانس ابعادی برابر

- 0.0508 mm/mm در جهت عمود بر مسیر فشرده شدن و
- 0.1016 mm per mm در جهت موازی با مسیر فشرده شدن تهیه کرد.

که این عمل توسط فشردن مجدد Repressing بعد از زینتر کردن میسر می شود که بنام سایز کردن مشهور است.



Impregnation and Infiltration

- It can be exploited to create special products by filling the available pore space with oils, polymers, or metals
- Impregnation: The term used when oil or other fluid is permeated into the pores of a sintered PM part
  - *Common products are oil-impregnated bearings, gears, and similar components*
  - *An alternative application is when parts are impregnated with polymer resins that seep into the pore spaces in liquid form and then solidify to create a **pressure tight part***
- Infiltration: An operation in which the pores of the PM part are filled with a molten metal
  - *The melting point of the filler metal must be lower*
  - *Involves heating the filler metal in contact with the sintered component so capillary action draws the filler into the pores*
  - *The resulting structure is relatively nonporous, and the infiltrated part has a more uniform density, as well as ... ... toughness and strength*

Impregnation

- It can be exploited to create special products by filling the available pore space with oils, polymers, or metals
- Impregnation: The term used when oil or other fluid is permeated into the pores of a sintered PM part
  - *Common products are oil-impregnated bearings, gears, and similar components*
  - *An alternative application is when parts are impregnated with polymer resins that seep into the pore spaces in liquid form and then solidify to create a pressure tight part*

Photo 3 Appearance of BMRC bushings

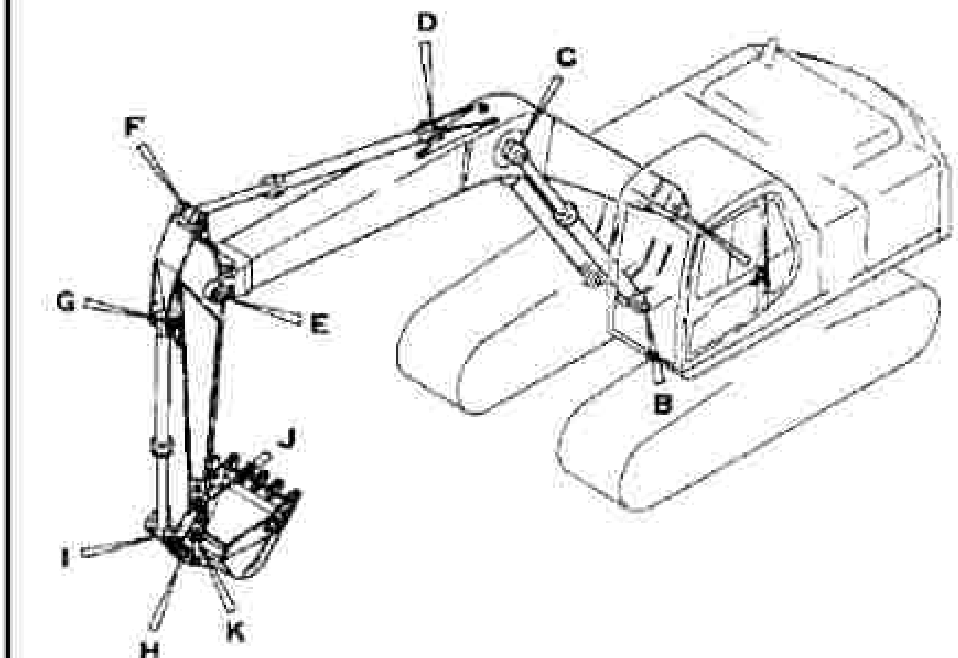
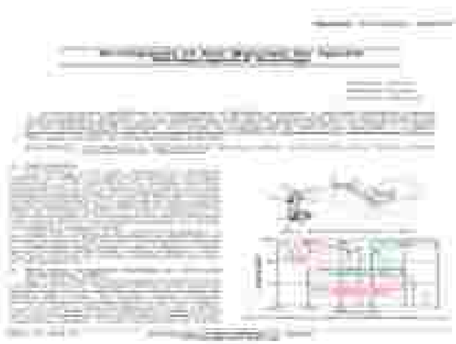


Fig. 1 Places where bushings are used



TECHNICAL REPORT

Development of New Materials for Special Oil-Impregnated Bearings

Photo 3 Appearance of BMRC bushings

Scheme of BMRC manufacturing process

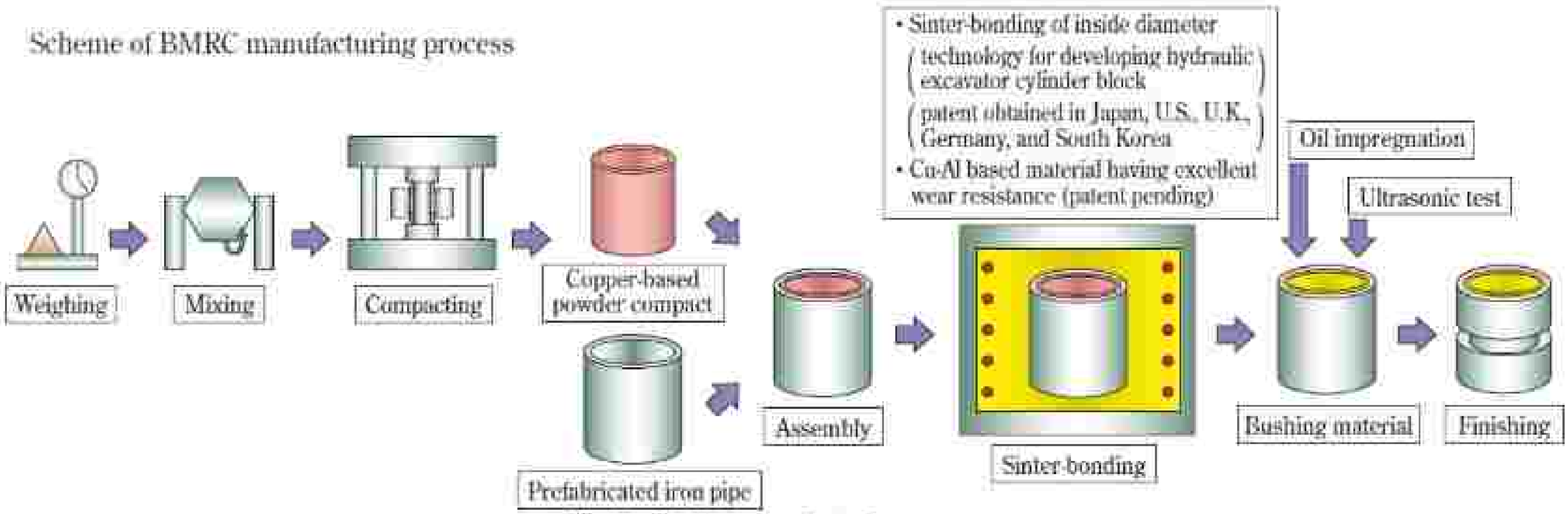
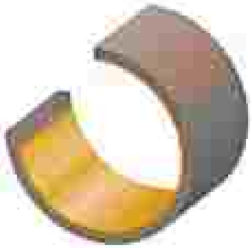
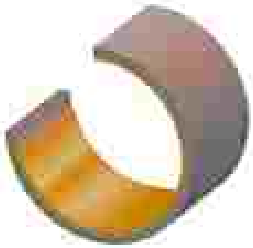
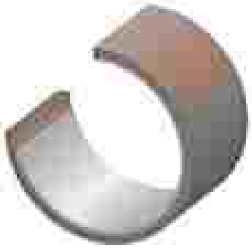


Fig. 5 BMRC manufacturing process

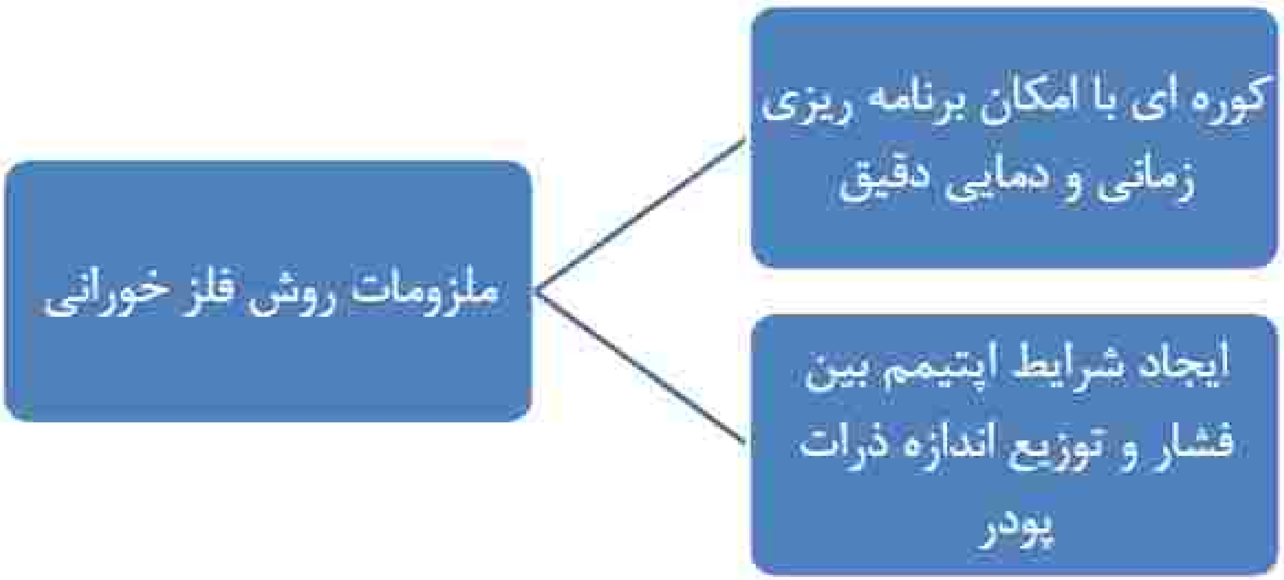
Data	800	720	700	20
Bimatel Bushing				
	Steel + $CuPb_{10}Sn_{10}$	Steel + $CuPb_{24}Sn_{4}$	Steel + $CuPb_{30}$	Steel + $AlSn_{20}Cu$

Impregnation and Infiltration

- <u>Infiltration:</u> An operation in which the pores of the PM part are filled with a molten metal
  - *The melting point of the filler metal must be lower*
  - *Involves heating the filler metal in contact with the sintered component so capillary action draws the filler into the pores*
  - *The resulting structure is relatively nonporous, and the infiltrated part has a more uniform density, as well as ……………. toughness and strength*

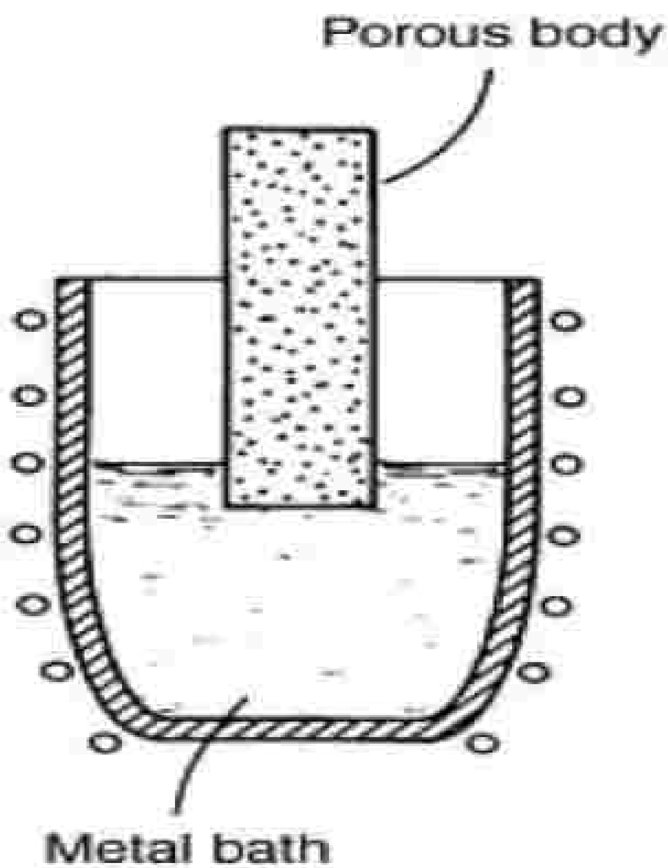
انواع روش های حصول حداکثر چگالی

فلزخورانی:۶۰



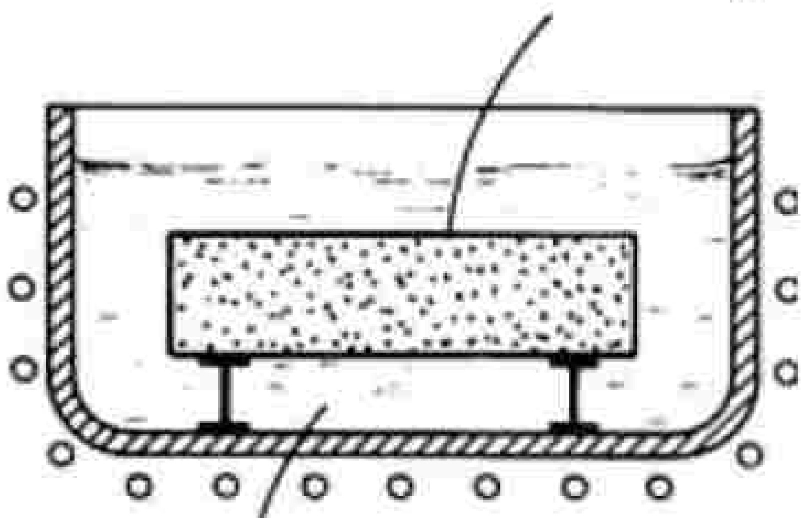
انواع روش های حصول حداکثر چگالی

۶. فلز خورانی از طریق(موئینگی-غوطه ور شدن):



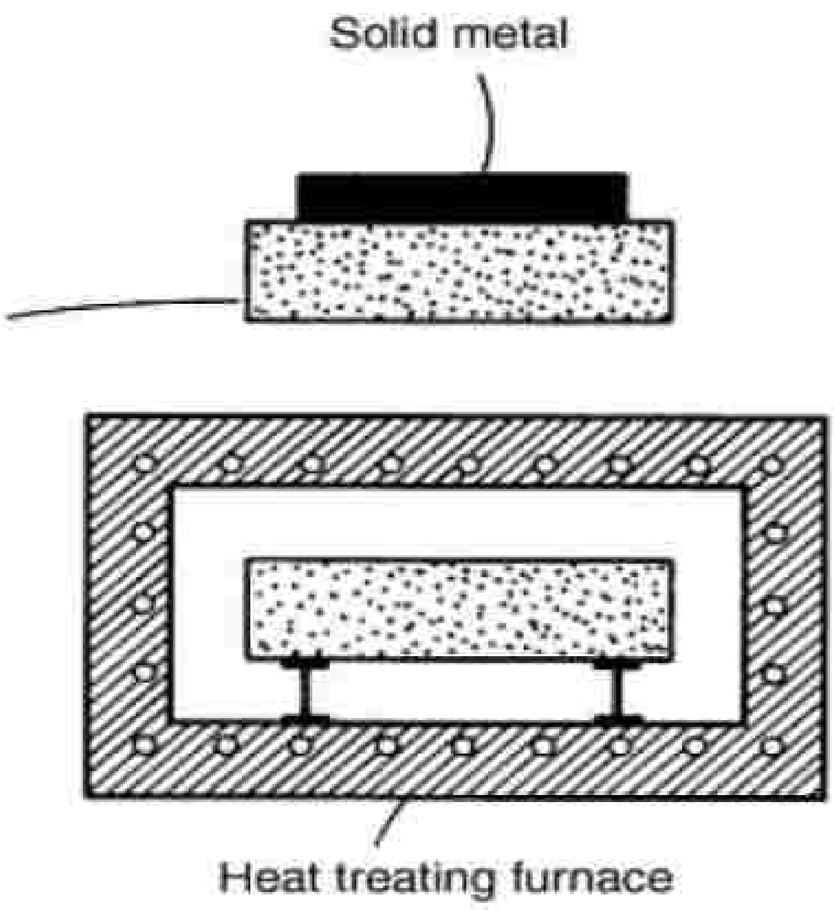
انواع روش های حصول حداکثر چگالی

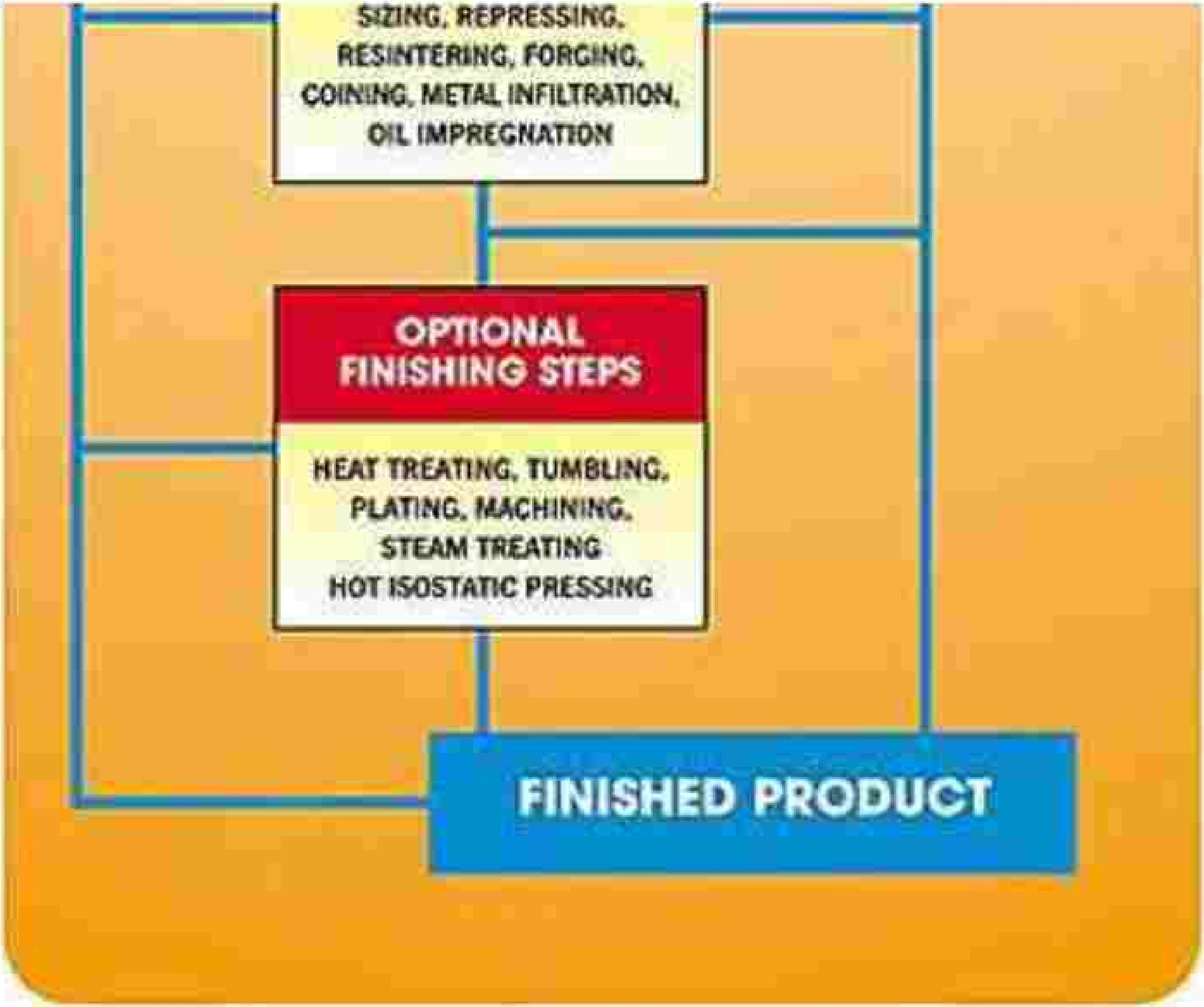
۲فلز خورانی از طریق غوطه وری ۶.
کامل:



انواع روش های حصول حداکثر چگالی

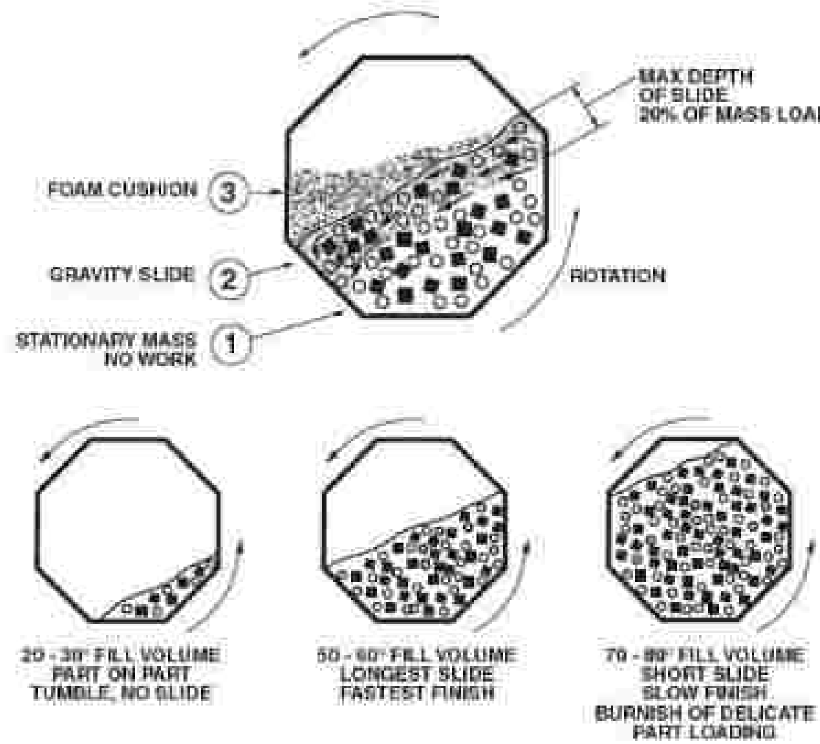
۳فلز خورانی از طریق تماس:۶۰




SIZING, REPRESSING,
RESINTERING, FORGING,
COINING, METAL INFILTRATION,
OIL IMPREGNATION
OPTIONAL
FINISHING STEPS
HEAT TREATING, TUMBLING,
PLATING, MACHINING,
STEAM TREATING
HOT ISOSTATIC PRESSING
FINISHED PRODUCT

BARREL TUMBLING

PARTS RATIO - 4 MEDIA TO 1 PARTS BY VOLUME.
USE AS A STARTING POINT.
CHANGE UP/DOWN TO ACHEIVE DESIRED RESULTS.



COMPOUND REQUIREMENTS

1. THICK - DURABLE
2. HEAVY FOAM - CUSHION FOR SOIL RETENTION
3. HIGH LUBRICITY - TO MAINTAIN A GOOD DEPTH OF SLIDE
4. SPEED, VARIABLE FROM 50 TO 200 S.F.M.
   SLOWER SPEED - BURNISHING   HIGHER SPEED - DEBURRING

Machine Tumbling

By utilizing our barrel tumblers either for part-on-part processing or in combination with media, Latem can effectively clean and deburr a very wide range of parts and part sizes. Tumbling can also be used as a cleaning process to remove stamping oils, heat treat scale, and burrs, often in one operation.

The tumbling process is rather simple. Parts are placed in a horizontal tumbling barrel, mixed with cleaning compounds and rust inhibitors, and often an abrasive media. The barrels are then rotated at anywhere from 20 to 40 RPM for a determined amount of time depending on the desired finish.

The barrel is designed to lift and move the parts so that they do not remain in the same formation throughout the process. The parts inside brush repeatedly against one another, and/or the media. This motion, along with the right compounds, makes for an effective cleaning process. Tumbling is the ideal process for smaller, more rigid parts.

Common finishes often achieved through tumbling include:

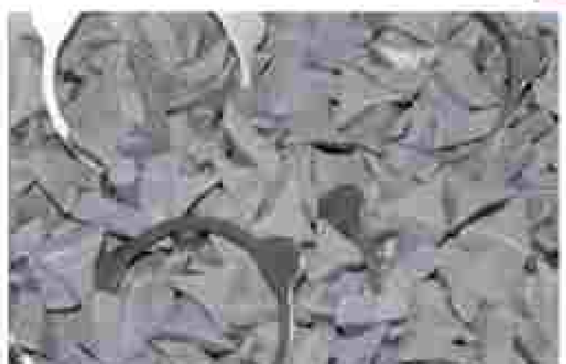
- Radiusing
- Deburring
- Cleaning
- Rust removal
- Surface hardening
- Edge breaking
- Removing heat treat scale
- De-flashing
- Brightening parts
- Preparing for further finishing/coating

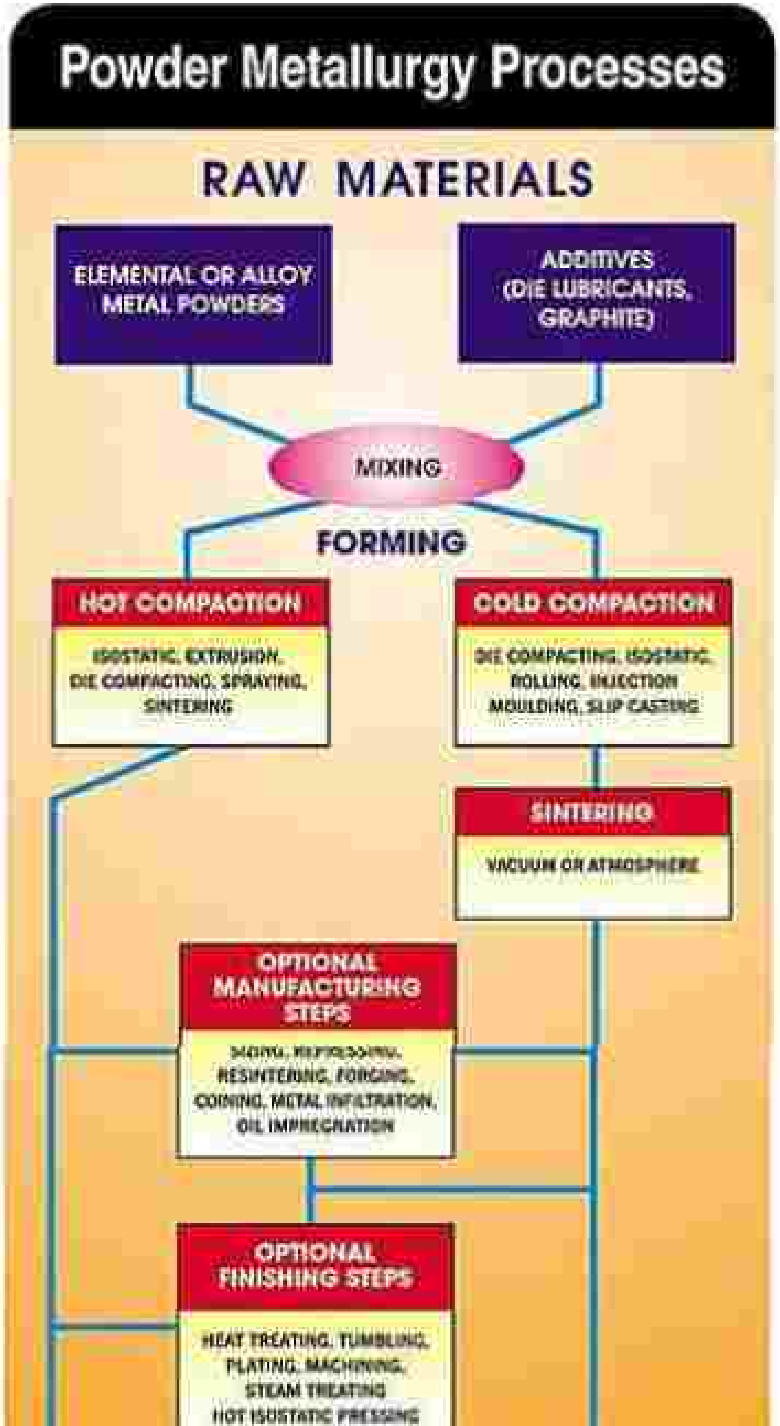
By utilizing barrel tumblers and using either media or part-on-part processes, we can effectively clean and deburr various sized parts. We can remove stamping oils, burrs and heat scale all in one op

Machine Tumbling vs Vibratory Finishing









Powder Metallurgy Processes
RAW MATERIALS
ELEMENTAL OR ALLOY METAL POWDERS
ADDITIVES (DIE LUBRICANTS, GRAPHITE)
MIXING
FORMING
HOT COMPACTION
ISOSTATIC, EXTRUSION, DIE COMPACTING, SPRAYING, SINTERING
COLD COMPACTION
DIE COMPACTING, ISOSTATIC, ROLLING, INJECTION MOULDING, SLIP CASTING
SINTERING
VACUUM OR ATMOSPHERE
OPTIONAL MANUFACTURING STEPS
RESINTERING, FORGING, COINING, METAL INFILTRATION, OIL IMPREGNATION
OPTIONAL FINISHING STEPS
HEAT TREATING, TUMBLING, PLATING, MACHINING, STEAM TREATING
HOT ISOSTATIC PRESSING

Production Sequence

- Procurement of raw materials needed for production of powdered metal part
- Mixing / Blending
- Compacting
- Sintering
- Post Treatments / Final Product

- Post Treatments" include, but not limited to; coining, sizing, closed forging, copper infiltration, machining, heat treatment, induction hardening, stream treatment, tumbling (deburring), shot blasting, shot peening, oil impregnation, and plating.