ISSN 2229-5518

Near net pressing of WC based hardmetal compacts in Cold Iso-static Pressing

Ajay P D[a], Ramesh S Rao[b], Dr. Rangaswamy T[c], Rengarajan R[b], Khilendra Kumar[b], Paniraj Shanbhog[b]

[a] Computational Analysis in Mechanical Sciences ,Government Engineering College, Hassan,573201,India
[b]Senior manager,R&D Kennametal India Limited, Banglore,560073,India
[c]Professor & Head of the Department ,Government Engineering College, Hassan,573201, India
[d]General manager R&D Kennametal India Limited, Banglore,560073,India
[e]Assistant manager Manufacturing Kennametal India Limited, Banglore,560073,India
[f]Senior manager Manufacturing Kennametal India Limited, Banglore,560073,India

Abstract: Cutting tools, Forming Dies and wear parts in tungsten carbide – cobalt (WC-Co) based hardmetals are manufactured using powder metallurgy route. One of the critical step is consolidation powder into a compact of approximately 55-65% of theoretical sintered density by Compaction. Subsequently compacts are sintered at temperature where cobalt used as metal binder is liquefied and almost 100% densification is achieved. The type of pressing is decided based on the size and complexity of the product. Cold Iso-static Pressing (CIP) is the most common pressing method when the size of the compact is more than 100mm. The CIP uses flexible rubber bags as a die and punches unlike Mechanical or Hydraulic presses where carbide itself is used as die and punches. Steel mill Rolls in hardmetal grades are one of the product manufactured through powder metallurgy route and used for manufacturing of steel wires through hot rolling process in steel industries. Since these are big in size and typically 216mm diameter after sintering, CIP is the most preferred compaction method. Since CIP uses flexible rubber bags, the surface of compacts would be irregular and green machining is very much necessary to achieve the near net shape. After compaction in CIP, typically the outer diameter is more at top and bottom portion of the roll and least at the middle. This irregular shape resembles foot of an elephant and hence called as elephant foot structure. Hence almost 40wt% of the material is green machined and the powders generated are re-processed resulting increased manufacturing cost and lead time. Hence the cost of pressing through CIP route is relatively high due to irregular surface. The main objective of this paper is to eliminate or reduce this elephant foot structure in WC-Co-Ni-Cr based powder pressed through CIP route to achieve near net shape and hence reduce green machining. In this paper contribution of Method of mould filling & replacement of PVC rubber bag by natural rubber bag is studied and are experimentally validated to understand its effect on elephant foot structure.

Keywords: WC-Co, Steel mill rolls, powder metallurgy, near net shaping, Cold Iso-static pressing, CIP, Green machining, pressing, hypothesis testing

Introduction

Defect free near net shaping of advanced ceramic powders into engineering components in large scale manufacturing has always been a challenge to engineers and component manufacturers. Among the powder compaction processes, isostatic pressing under cold (CIP) or hot (HIP) conditions is expected to provide parts with high density as well as isotropic properties. In cold isostatic pressing, powder is pressed in a container pressure vessel under isostatic compression **P.Beiss(2003).,**[1] studied application of pressure and compaction of powders with green strength during isostatic compaction. After sealing, the molds are inserted in the pressure chamber of a cold isostatic press & compacted by pressurizing with in a

ISSN 2229-5518

fluid **P.Beiss(2003).,**[2] studied that in cold isostatic pressing, powder is compacted in a deformable container ideally in a pressure vessel under isostatic triaxial compression . Rolls for hot rolling of steel wires are being manufactured in WC based hardmetal grades with alloy binder system (Cobalt-Nickel-Chromium) in different sizes through powder metallurgy route comprising sequential process steps of Powder manufacturing, Powder compaction in Cold Iso-static Press, Machining of Green parts, densification by Sintering and Hipping. Throughout the system the powder is poured inside the rubber bag which contains steel core rod, the rubber bag & metal mantle is placed inside the steel container. The mantle is centered on a lower steel base plate which also accepts the core rod. During filling of powder, the mold is tapped to approximate the filling density to tap density. Then an upper rubber cap closes the container which is finally sealed with rubber caps & tight metallic strips. The whole assembly is inserted into the vessel of cold isostatic press which is pumped to maximum pressure of up to 2200bar in production facilities. After pressurizing, the pressure is slowly released & the rubber member expands to its original diameter. The mold is lifted out of the vessel, cleaned & refilled. Because of variation in pressure distribution on the powder, the compaction of powder varies along the diameter. It can be observed that the diameter at top and bottom of the compact is larger than diameter at the middle which is termed as elephant foot structure as shown in Fig-1. The occurrence of this irregular shape, almost 40wt% of the material is green machined and the powders generated are re-processed resulting in increased manufacturing lead time, reduces machine capacity, increase in powder re-processing. A common defect in CIP product is the distortion of the manufactured component. **Xu** and **McMeeking(1992).,**[3] studied recently effects of the canister on shape change and concluded that the final shape change of CIPed components depends strongly on the can design. Susumu **Shima, Yuuki Sakamoto** and **Hidetoshi Kotera(2002).,** [4] analyzed an elastic- plastic FEM to study the fundamental feature of the rubber isostatic pressing of the stainless steel powder with a view to performing a net shape process. Experiments are also performed. It is thus shown that the properties of rubber, in particular Poisson's ratio, give a great influence on the shape of the compact and density distribution. The thickness of the rubber is also influential; thicker the mold, the closer is the shape of the compact to the cavity shape.

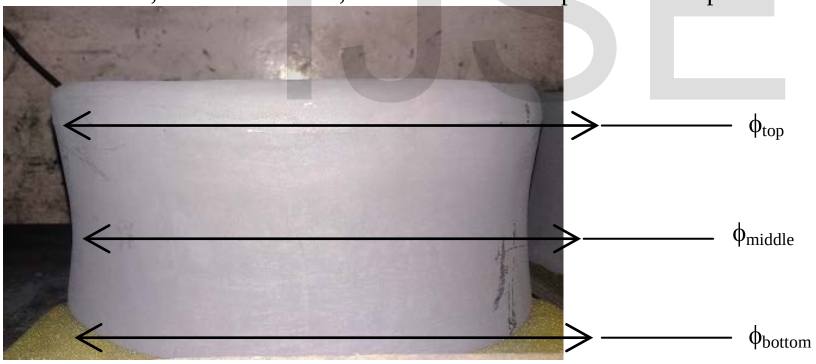

Fig-1. Elephant Foot Structure after pressing in CIP

The mathematical formula is formulated for elephant foot structure and is given by equation (1) with reference to top side of the roll and equation (2) for bottom side of the roll.

Elephant foot structure at top $\mathbf{R_{e\text{-}top}}=(\phi_{top}-\phi_{middle})/\ \phi_{middle}$ …….(1)

Elephant foot structure at bottom $\mathbf{R_{e\text{-}bottom}}=(\phi_{bottom}-\phi_{middle})/\ \phi_{middle}$ …….(2)

Where ϕ_{top} = diameter of green roll compact at top side in mm, ϕ_{middle} = diameter of green roll compact at

ISSN 2229-5518
middle in mm, ϕ_{bottom} = diameter of green roll compact at bottom side in mm and the diameter is measured using a calibrated Vernier calliper.

1. Current State Data

When components are consolidated from metal powders by isostatic pressing, substantial shape changes occur. Even though the pressure applied in cold isostatic pressing is in isostatic manner, various phenomena conspire to impose change in shape. It was observed that end portion of the compact appears to be larger in diameter than middle portion this is commonly called **Elephant foot (Re)**. Current state data in elephant foot has been collected for 46 Rolls which are typically of 216mm sintered diameter with inner diameter of 90mm and height 70mm. The properties of hardmetal grade are shown in Table-1 and the current elephant foot structure is illustrated in Table-2

Table-1. Properties of hardmetal grade used for this study

Grade Name	**Metallic Alloy Binder content wt%**	**Target Sintered Density, g/cm^3**	**Carbide Grain size**	**Target Sintered Hardness Hv**
A	15	14.00	Coarse	1000

Table-2. Current elephant foot structure at top and bottom of Rolls.

	Average	**Standard Deviation**	**Median**
Elephant foot at Top, $R_{e\text{-}top}$	0.020726 (=2.0726%)	0.007451	0.018739 (=1.8739%)
Elephant foot at Bottom, $R_{e\text{-}bottom}$	0.020184 (=2.0184%)	0.007210	0.019504 (=1.995%)

3 Experimental Setup

In this paper the effect of powder filling method in the rubber mould and the mold material along with mould thickness on the elephant foot structure is studied.

3.1 Mold Filling method

In the regular method the filling of powder inside the container is carried out by manual feeding and the packing of powder inside the container is carried out by using a tapping machine. Also after tapping once the powder level reaches certain height the manual hand ramming is carried out. However In this experiment, powder filling method is changed by using a vibratory machine instead of manual tapping as shown in Fig-2.

During this process, the container is kept in vibratory machine and it is vibrated, the powder is poured inside the container. Once the required weight of powder is filled, container is vibrated up to 15minutes. At the end, machine tapping is done to consolidate the powder to achieve initial fill density. In this process the manual tapping is eliminated and container is directly kept inside the CIP vessel. This procedure is carried out for two rolls and the variations are observed. By changing the method of powder filling we observed the there is considerable change in shape of the rolls after pressing in CIP as shown in Fig-3 and elephant foot data is shown in Table-3.

Table-3 Elephant foot data for rolls processed with vibrational filling methods

Sl. No.	Compact Diamter at Top, mm	Compact diamter at Middle, mm	Compact diamter at Bottom, mm	Elephant foot structure at Top, $R_{e\text{-}top}$	Elephant foot structure at Bottom, $R_{e\text{-}bottom}$
1	263.2	261.7	269.49	0.005540	0.028758
2	262.4	260.4	268.46	0.007526	0.029874
			Avearge	**0.006533 (=0.6533%)**	**0.029316 (=2.9316%)**

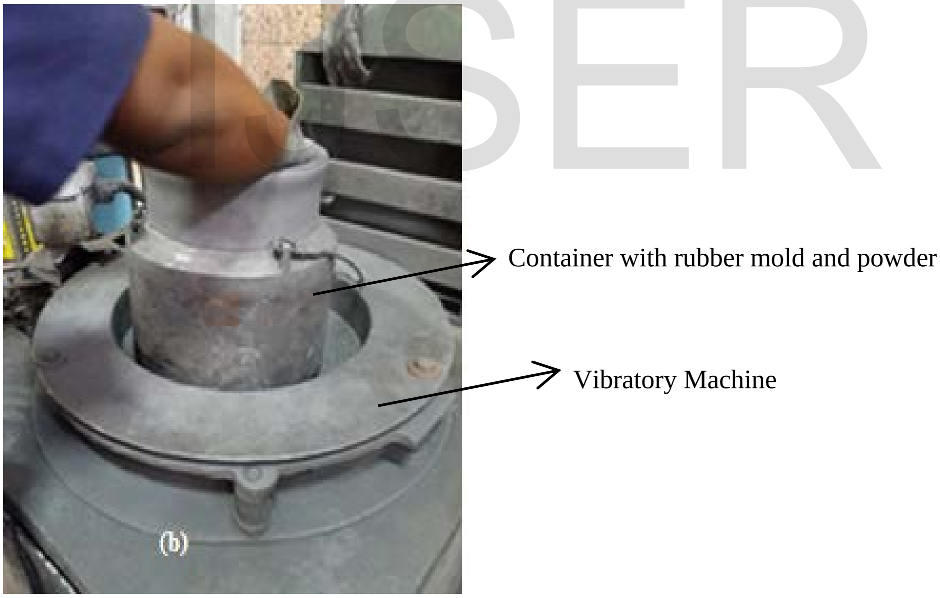

Fig 2 Vibrational method of powder filling

It is observed from Table-3 that, after adopting the vibrational method of powder filling the $R_{e\text{-}top}$ is reduced considerably compared to normal method. For the two rolls processed by vibrational method average elephant foot structure at top $R_{e\text{-}top}$ is 0.006533 versus 0.020726 for the conventional method. From One-sample t-test

International Journal of Scientific & Engineering Research, Volume 8, Issue 1, January-2017
1475
ISSN 2229-5518
as shown in Table-4, there is signifcant improvemet in elephant foot at top diameter after change in the powder milling method. However average elephant foot structure at botoom, Re-bottom increased to 0.029316 from 0.020184 for the conventional method. From One-sample t-test as shown in Table-5, there is signifcant increase in elephant foot at bottom diameter after change in the powder milling method.

Fig 3 Roll pressed after adopting vibrational method while powder milling

Table-4 One-Sample t-Test result for powder filled by Vibrational method – for diameter at top

Null Hypothesis Ho: The $R_{e\text{-top}}$ with new vibrator filling (0.00653) is equal to $R_{e\text{-top}}$ with conventional manual filling (0.020726)
Alternate Hypothesis H1: The $R_{e\text{-top}}$ with new vibrator filling (0.00653) is not equal to $R_{e\text{-top}}$ with conventional manual filling (0.020726)
Confidence Interval = 95%, α=5% (0.05)
Test of μ = 0.0065 vs $\neq$ 0.0065

N	Mean	StDev	SE Mean	95% CI	T	P
46	0.02073	0.00745	0.00110	(0.01851, 0.02294)	12.95	0.000

Since p-value is <0.05 → Reject Ho.
$R_{e\text{-top}}$ Reduced from 2.0726% to 0.653% after using Vibrational powder filling

Table-5 One-Sample t-Test result for powder filled by Vibrational method – for diameter at bottom

Null Hypothesis Ho: The $R_{e\text{-bottom}}$ with new vibrator filling (0.029316) is equal to $R_{e\text{-bottom}}$ with conventional manual filling (0.020184)
Alternate Hypothesis H1: The $R_{e\text{-bottom}}$ with new vibrator filling (0.029316) is not equal to $R_{e\text{-bottom}}$ with conventional manual filling (0.020184)
Confidence Interval = 95%, α=5% (0.05)

Test of μ = 0.029316 vs ≠ 0.029316

N	Mean	StDev	SE Mean	95% CI	T	P
46	0.02018	0.00721	0.00106	(0.01804, 0.02233)	-9.42	0.000

Since p-value is <0.05 → Reject Ho.
$R_{e\text{-bottom}}$ increased from 2.0184% to 2.9316% after using Vibrational powder filling

By adopting the vibrational method of powder filling the diameter of the rolls at the top is reduced but the reduction in diameter at the bottom is relatively less when compared to the normal method. This is due to the fact that, with the powder filling by vibrational method, the desired initial powder packing density is not achieved forcing to do machine tapping. Introduction of machine tapping resulted in packing of powder at the bottom and hence less shrinkage during powder compaction. However when compared to conventional method, vibratory powder filling method helps to improve the compact shape. Further modifications to vibrational frequency, machine tapping, time could improve the elephant foot structure..

3.2. Replace PVC rubber bag by Natural rubber molding bag with uniform thickness

The rubber bag which is conventionally used in CIP process is made up of PVC material and the thickness of rubber bag is not constant along the length and diameter. To determine the effect of rubber bag thickness and rubber bag material, the PVC rubber bag is replaced by natural rubber which is having uniform thickness of 3mm at top, middle and bottom. The rubber bags used in conventional method and current experiment are shown in Fig-4.

ISSN 2229-5518

Fig 4 (a) Rubber bag madeup of PVC, (b) rubber bag madeup of natural rubber with uniform thickness

By changing the rubber bag material, one roll is processed and we observed that there is considerable change in shape of the rolls after pressing in CIP as shown in Fig-5 and elephant foot data is shown in Table-6. However, for this trial atomized granualted hardmetal powder is used instead of a vacuum dried fine powder.

Table-6 Elephant foot data for rolls processed with natural rubber as molding bag

Sl. No.	**Compact Diamter at Top, mm**	**Compact diamter at Middle, mm**	**Compact diamter at Bottom, mm**	**Elephant foot structure at Top, $R_{e\text{-}top}$**	**Elephant foot structure at Bottom, $R_{e\text{-}bottom}$**
1	263.24	260.15	263.94	0.011878	0.014359

ISSN 2229-5518

Fig-5. Roll pressed after changing the rubber bag material to natural rubber with uniform thickness.

It is observed from Table-6 that, after changing the bag material to natural rubber of uniform thickness, $R_{e\text{-}top}$ is reduced considerably compared to normal method. For the roll processed with natural rubber bag, elephant foot structure at top $R_{e\text{-}top}$ is 0.011878 versus 0.020726 for the conventional method. Similar trend observed for elephant foot structure at bottom, $R_{e\text{-}bottom}$ also reduced to 0.014359 from 0.020184 for the conventional method. From One-sample t-test as shown in Table-7 & Table-8, there is signifcant reduction in elephant foot at top diameter and bottom respectively after change in the bag material

Table-7 One-Sample t-Test result for change in bag material – for diameter at top

Null Hypothesis Ho: The $R_{e\text{-}top}$ with natural rubber & uniform thickness (0.011878) is equal to $R_{e\text{-}top}$ with PVC bag (0.020726)

Alternate Hypothesis H1: The $R_{e\text{-}top}$ with natural rubber & uniform thickness (0.011878) is not equal to $R_{e\text{-}top}$ with PVC bag (0.020726)

Confidence Interval = 95%, α=5% (0.05)

Test of μ = 0.011878 vs $\neq$ 0.011878

N	Mean	StDev	SE Mean	95% CI	T	P
46	0.02073	0.00745	0.00110	(0.01851, 0.02294)	8.03	0.000

Since p-value is <0.05 → Reject Ho.

$R_{e\text{-}top}$ Reduced from 2.0726% to 1.1878% after using natural rubber with uniform 3mm thickness

Table-8 One-Sample t-Test result for change in bag material – for diameter at bottom

ISSN 2229-5518

Null Hypothesis Ho: The $R_{e\text{-bottom}}$ with natural rubber & uniform thickness (0.014359) is equal to $R_{e\text{-bottom}}$ with PVC bag (0.020184)
Alternate Hypothesis H1: The $R_{e\text{-bottom}}$ with natural rubber & uniform thickness (0.014359) is not equal to $R_{e\text{-bottom}}$ with PVC bag (0.020184)

Confidence Interval = 95%, α=5% (0.05)
Test of $\mu = 0.014359$ vs $\neq 0.014359$

N	Mean	StDev	SE Mean	95% CI	T	P
46	0.02018	0.00721	0.00106	(0.01804, 0.02233)	5.48	0.000

Since p-value is <0.05 → Reject Ho.
$R_{e\text{-bottom}}$ reduced from 2.0184% to 1.4359% after using natural rubber with uniform 3mm thickness

By replacing PVC rubber of non-uniform thickness by natural rubber with unfirm 3mm thickness, signifcant reduction in elephant foot ratio observed both at top and bottom. It is also observed that the natural rubber sustained a maximum pressing pressure without any crack or damage. However the main disadvantage with using natural rubber bag is its poor elastic property. This resulted in difficulty in folding the rubber bag during the sealing stage before pressing and also while removing the compact from bag after pressing.

During this trial, it was observed that there are thicker sections at the bottom of natural rubber bag as shown in Fig-6. When the powder is filled and compacted, relative volume of powder is less in this portion and hence more shrinkage observed during compaction as shown in Fig-7. With this concept, elephant foot can be reduced by increasing the thickness at top and bottom of the rubber bag and hence by increasing the pressing shrinkage at top and bottom in relation to middle portion of the compact.

Fig-6 More thicker portions observed near bottom of rubber bag

Fig-7 The reduction in diameter observed near thicker portions of rubber bag at bottom

4. Conclusion

In this study, two parameters which influence the net shaping of compacts pressed in Cold Iso-static Press are studied and following conclusions can be drawn from this study.

1. The Vibrational method of powder filling greatly influences the net shape of a powder compacted through CIP. The powder is filled inside the container simultaneously the container is vibrated such that the

settlement of the powder takes places and it leads to uniform initial fill density of a powder. However with this method, powder fill density reduced and hence we were unable to load the required powder weight. By using a machine tapping, powder fill density is increased but elephant foot structure at bottom increased. However this method significantly reduced the elephant foot structure at top side of the compacted roll.

2. By replacing PVC rubber bag of non-uniform thickness by natural rubber bag with uniform 3mm thickness, there is a considerable amount of shape change and hence reduction in elephant foot structure at top and bottom diameter of roll. Also it was observed that natural rubber bag could withstand the pressing pressure without any damage or crack even though it is much stiffer than PVC rubber bag, However there was a difficulty in which removing the compact from the bag after pressing.

3. Elephant foot structure can be reduced by increasing the thickness at top and bottom of the rubber bag and hence by increasing the pressing shrinkage at top and bottom compared to middle portion of the compact.

Reference

[1] P. Beiss. "Uniaxial compaction in rigid dies",Landolt-Börnstein - Group VIII Advanced Materials and Technologies, 2003.

[2] P. Beiss. "Isostatic and pseudoisostatic compaction", Landolt-Bornstein - Group VIII Advanced Materials and Technologies, 2003

[3] R.M McMeeking "The Analysis of Shape Change During Isostaic Pressing",Int J.Mech Sci,Vol 34,pp 53-62,1992.

[4] Susumu Shima,Yuuki Sakamoto,Hidetoshi Kotera "Simulatuion of Rubber Isostatic Pressing and Shape Optimization"-J.Mech, Vol 44,pp1603-1623, 2002.