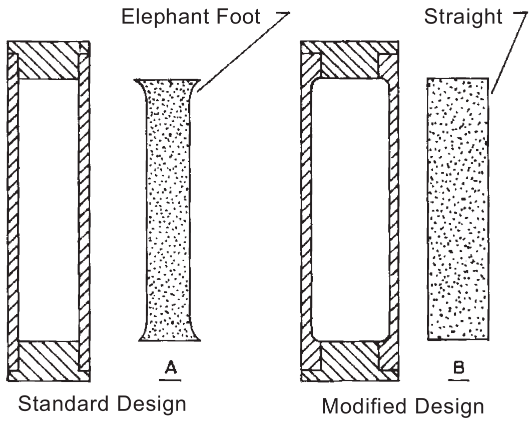

Fig. 5.16 Modified tooling design for cold isostatic pressing.[7]

5.3.4 Cold Isostatic Applications

Some examples of applications taken from industrial processes in use today can be listed below:

Graphite: Cold isostatic pressing of electrographite, refractory graphite and graphite used in nuclear reactors.

Ceramics: Cold isostatic pressing of tubes, tiles, nozzles and linings made out of special ceramics.

Ferrites: Parts used for permanent magnets, computer memories, electronics etc.

Cemented Carbides: Cold isostatic pressing to preform powder products.

Metal Powder: High speed tool steels, superalloys, stainless steel, titanium alloys, beryllium etc.

5.4 Dynamic Powder Compaction

Dynamic powder compaction is a single compaction/ sintering operation brought about by the impact of a high speed punch on powder. This produces a discrete shock wave in the powder, which under optimized conditions, results in metallurgical bonding and sometimes fusion of the particles surface. The work of compaction produced by inter particle shear is transferred on the surface of the powders in such a short time (microseconds or less) that there is no possibility for heat to be conducted away from the surface and thus localized melting or welding occurs. The welding is similar to that which occurs during the seizure of a bearing or during friction or explosive welding. The production of greater than 99% theoretical density compacts is facilitated by the inter particle lubrication that the melted surface of the particle provides. The temperature rise of the interior of each particle is small. Dynamic powder compaction differs from such high speed techniques as Petro forge or Dynapak, in that the latter processes are closely related to crank presses and drop forges. They involve large mass travelling at a low velocity, whilst dynamic powder compaction involves a very light punch travelling at a very high velocity. The actual compaction press consists of a high pressure reservoir, fast action valve, guide tube, compaction chamber and ejector unit. Compressed air is usually used as the drive system. At very high velocities helium may be used. It has been noticed that in dynamic powder compaction, the liquid zone between the particles resolidifies in the same time scale as its formation. This is in the range $10^6 – 10^8$°C/sec. These cooling rates result in a rapidly solidified material with an extremely fine structure or even an amorphous glassy structure. Such a rapidly solidified material imparts unique properties to the compacts. Depending upon the material, the weld zone may have a hardness above or below that of the work hardened particles. Heat treatments may be given to bring out a specific property in either the weld zone or the particles. For instance, the rapidly quenched weld zone may be given an ageing treatment or the heavily work hardened particles may be made to recrystallize.

Among possible applications, the process allows nonequilibrium powder or powder mixtures to be consolidated with neither chemical reactions nor a degeneration of metallurgical structures. For example, aluminium compacts with very good wear and seizure resistance have been made from Al-steel mixed powders. Conventional sintering of these would result in the formation of a brittle intermetallic. It is also possible to compact add-mixed carbides in steels.

In an extreme case, it has been possible to consolidate amorphous materials without crystallization occurring. The finer grain size, higher solute contents, uniform alloy distribution and cleanness of the powder make rapidly solidified powders of great interest for many demanding applications, especially with regard to superalloys and aluminium alloys for aircraft. Dynamic powder compaction can also consolidate nonmetals and again several interesting possibilities exist in this area.[9]

5.5 Powder Roll Compaction

Powder rolling, also called roll compacting, is the important process to produce metal strips. In powder rolling metal powder is fed from a hopper into gap of a rolling mill and emerges from the gap as a continuous compacted green strip. The rolls of the mill may be arranged vertically or horizontally. The latter type of arrangement is more common, with either saturated feed or starved feed.[2]

The powder characteristics have the following effect on powder rolling:

Particle Shape: The generation of maximum 'green' strip strength to withstand the rigours of handling through the process line require the particle shape to be very irregular.

Compressibility: Good compressibility is required to ensure that sufficient particle interlocking takes place to give adequate 'green' strip strength. Good green strip has a density of at least 80/85 % theoretical. Compressibility is also of importance in determining the limiting dimensions of the roll compaction mill.

Particle Size: The thickness of the finished strip and particle segregation severely restricts the maximum particle size which can be tolerated in the powder feed to the compaction mill.

Flowability: The powder must flow smoothly and quickly through hopper systems with minimum tendency to stick slip or bridging.

Surface Oxidation: This plays a significant part in determining subsequent powder behaviour.

The roll compaction operation can be divided into three distinct zones (Fig.5.17):

1. The free zone where blended powder in the hopper is transported freely downward under gravity. Here all the usual criteria of hopper flow apply.

2. The feed zone where the powder is being dragged by the roll surface into the mill bite, but has not yet attained coherence.

3. The compaction zone close to the roll nip, where the powder becomes coherent, the density changes rapidly and air has to be expelled.

In contrast to conventional rolling, the thickness of the strip can be rolled in powder rolling is closely limited by the diameter of the rolling mill rolls. The change in density is accomplished as the powder is transported through the feed zone and the compacting zone. The length of these zones is determined by the diameter of the rolls (D), the internal friction between the powder particles and the friction between powder and rolls. With the geometry shown in Figure 5.17, the nip angle α may be defined as

$$\cos \alpha = \frac{x}{D/2}$$

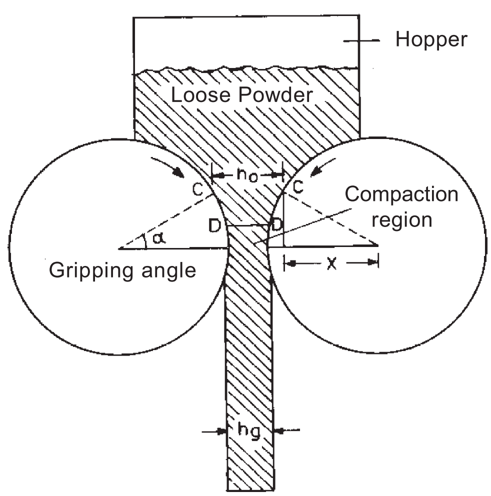

Fig. 5.17 Schematic of powder rolling with saturated feed, rolling mill rolls arranged horizontally.[6]

The dimension h_0 would be equal to $D(1–\cos \alpha) + H_g$. The strip thickness h_g is equal to h_0/C, where C is the compression ratio. The strip thickness would then be

$$H_g = \frac{D(1 - \cos \alpha)}{C - 1}$$

Evans and Smith[8] showed that, due to slipping between powder particles, the actual angle at which the powder is gripped is much lower than the calculated friction angle, *f*. As a result it is found that in order to roll compact a certain thickness of strip it is necessary to use very much larger diameter rolls than are required for producing similar strip from solid material. Roll diameters of between 50 and 150 times the strip thickness are often required. The maximum strip thickness can be increased by increasing the

'μ' i.e. by roughening the roll surface, although during rolling the conditions change as the surface ultimately gets polished. Figure 5.18 shows the strip thickness that can be obtained with different roll diameters with two types of nickel powders.

The green powder strip should have uniform thickness and density across the width of the strip, and its edges should be well formed and as dense as the centre of the strip. Edge controlling is, therefore, essential to process control. Figure 5.19 illustrates typical methods for such a control.[6] In Fig.5.19a floating flanges that are attached to one roll and that overlap the other roll are used. Pressure is applied to the flange as they approach the roll gap, thus preventing powder loss from the gap. A continuous belt that covers the gap at edge of the rolls also is effective in preventing powder loss (Fig.5.19b).

If the air entrapped in the powder is not properly released, the distur-

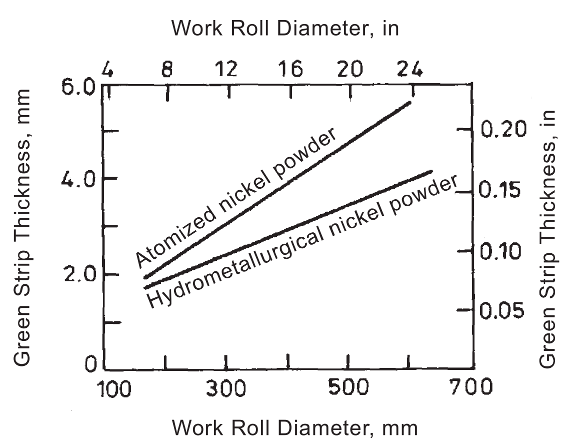

Fig. 5.18 Effect of work roll diameter on green strip thickness for two types of nickel powder.[6]

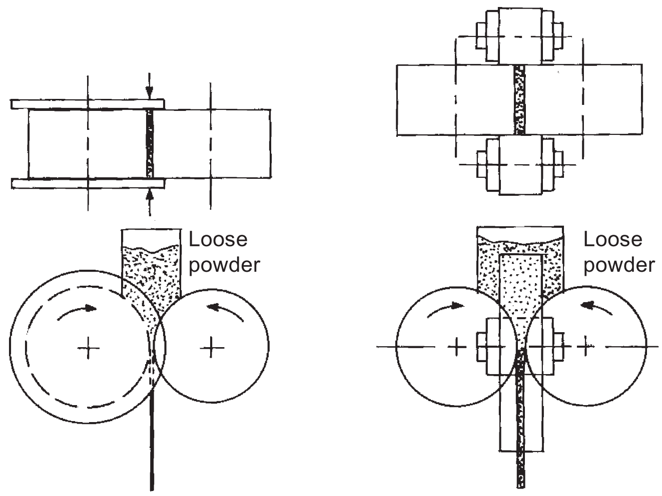

Fig. 5.19 Methods of controlling powder feed to compacting rolls (a) flange edge control; (b) belt edge control.[6]

bance of the powder in the hopper can be sufficient to interface with the smooth flow of powder to the roll nip and the strip produced will not be of uniform density. Up to a given speed, called the 'flow transition speed', the flow rate of powder increases linearly with roll speed. Above this critical speed, relatively less and less powder flows into the roll gap, until at speeds considerably above the transition speed, continuous strip can no larger be rolled.

Subsequent to green strip formation, the next operation is sintering, in which the strip shrinks in all three dimensions depending as process parameters and material composition. For all applications except porous strip, the sintered strip is rerolled. In one of the scheme; in order to obtain completely dense strip, addition cold rolling and annealing steps are incorporated in the total cycle. The main problem with this type of mill is to synchronize the rate of rolling with that of sintering and annealing. In another scheme, the rolled strip is fed into a continuous sintering furnace, from where it goes to cooling zone and then on a coiler. This coiled strip is rerolled and annealed in separate operation. In another modification, the coiled green strip is sintered as such. In such types of schemes, the difficulties with synchronization are either partially or completely removed.

In addition to using powder rolling for the large scale production of strip and sheet of base metal and alloys, the technique has also been employed for a number of speciality type strip materials, e.g. nickel and cobalt alloys for electronic and magnetic applications, porous powder rolled strip, in particular stainless steel strip for filters and nickel strip for electrodes and also an aluminium alloy strip for bearing applications.

Another speciality application of roll compaction is the production of bimetallic strip consisting of layer of Al–8.5 Pb–4.0 Si–1.5 Sn–1.0 Cu prealloyed powder sandwiched to a pure aluminium layer. For such a production, three powder hoppers are required as well as a powder flow blade that controls the flow of the powders into the roll gap. The coil of the composite strip is then sintered, and eventually the pure aluminium layer is roll bonded to a steel backing material.

References

1. S. Bradbury (Ed.), Powder Metallurgy Equipment Manual, 3rd Edition, MPIF, Princeton, 1986, p. 42.
2. F.V. Lenel, Powder Metallurgy Principles and Applications, MPIF, Princeton, 1980, p. 128.
3. R.N. Kunkel, Tooling Design for powder metallurgy parts, American Society of Tool and Manufacturing Engineers, Dearborn, 1968, p. 26.
4. K.J. Morris, In 'Isostatic Pressing Technology", Ed. P.J. James, Applied Science Publishers, Barking, 1983, p. 102.
5. Powder Metallurgy Design Manual, 2nd edition, MPIF, Princeton, 1995.
6. Metals Hand Book, Vol.7, Powder Metallurgy, ASM International, Material Park, Ohio, 1984, p. 327.
7. R.M. Broughton, Flexible Tooling for Cold Isostatic Pressing, Brochure by Watts Urethane Products Ltd., U.K.
8. P.E.Evans and G.C.Smith, *Powder Metallurgy*, No.3,1959, 1.
9. D. Raybould, *Metal Powder Report*, Vol.35, No.10, 1980, 467–469.