

Powder Injection and Formation of Porosity in Spray Forming

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A device for injecting powders into the spray cone during spray compaction is described and tested. The aim was to make the rate of powder injection and the spatial distribution of powders in the deposit as homogeneous as possible. The function of the device is demonstrated by injecting aluminium particles into a steel melt during atomisation and by measuring the concentration profile of aluminium in the resulting deposit. As an application porous deposits are created by injection a substance creating large volumes of gas in the deposit.

1. Introduction

Spray forming is a process which allows for manufacturing a large number of different materials having properties which are typical for the spray process such as low oxide contents, fine grains, or a high content of metastable alloy phases. These properties usually can not be achieved by conventional casting methods [1]. One feature makes the spray process appear especially attractive: the possibility of modifying the properties of the deposit by injecting powders such as oxides, carbides or pure metals into the spray cone and allowing them to react with or to be wetted by the liquid metal droplets and to be incorporated into the metal as it is deposited on the substrate. This way metal matrix composites (MMCs) can be made if the added powders are carbides or oxides. Examples of such spray formed MMCs are SiC in aluminium [2], graphite in copper [3], or alumina in steel [3]. An other application of powder injection is what is called reaction spray forming, where the powders react with the liquid metal to form some product which is then incorporated into the deposit. An example for this is the formation of alumina in copper by adding copper oxide to a copper melt containing small amounts of aluminium [3,4]. Finally, the powders injected may be substances which decompose when they come into contact with the metal and release large amounts of gas. The gas then might generate pores in the deposit. This effect - usually undesired - could help to make highly porous materials for structural or functional applications based on copper [5] or steel [6]. If the level of porosity exceeds 50%, such structures are called metal foams [7].

For making MMCs large quantities of powder have to be injected into the spray cone to ensure that the final oxide or carbide content in the metal ranges above 20% which is about the minimum content usually needed to achieve attractive mechanical properties of the MMC. For the reaction spray forming or the foam making process, however, lower powder contents can be sufficient. Crucial for the advantageous mechanical properties of such MMCs, foams etc. is the ability of dispersing the powders homogeneously in the metal matrix.

The aim of the present work was to construct a device for injecting comparatively low quantities of powder at a constant rate. The powders injected were supposed to form pores ("foam spraying") or to react with the liquid ("reaction spraying"). The present article describes the injection device constructed for this purpose and the results of test runs where various powders were injected in small quantities. The resulting distribution of the corresponding elements was measured in the deposit. Gas releasing substances were injected in a second experiment to trigger pore formation deliberately.

2. Injection device

2.1 General considerations

There are various concepts for injecting powders into the spray cone. Unfortunately, there is virtually no published literature yet where the function of powder injection devices is described in detail and mostly merely general concepts are given. Two tasks have to be solved when one wants to inject powder: firstly, one has to transport a given quantity of powder per unit time from a reservoir into some pre-chamber, secondly, one has to blow the powder from this chamber into the spray cone. For the first task a multitude of possible solutions have been proposed including disc feeders, various types of screw feeders or pneumatic devices. For the second task - the injection of the powder into the spray cone - various ways have been proposed in literature as shown in schematical form in Fig. 1: either by letting the powder being transported by the atomising gas itself (c), or by injecting it into the spray cone from the side by using a separate transport gas stream (a,b).

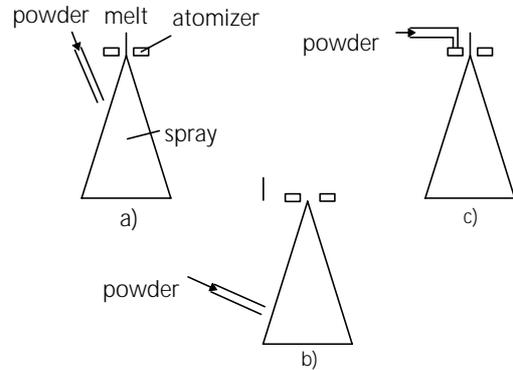


Fig. 1: Schematical sketch of the various possibilities for injecting powders into a spray cone [3].

The advantage of the first possibility is that the powders are transported directly into the atomising zone by means of the atomising gas and that the interaction between powder particles and metal droplets is expected to be very intense this way. Moreover, overspray losses can be expected to be comparatively low and the resulting particle distribution in the sprayed deposit is believed to be more homogeneous. A disadvantage is that the pressure and flow rate of the atomising gas is usually given by the atomisation conditions and can not be varied in order to manipulate the transport conditions of the powder particles. Moreover, many powders are abrasive and over the time might change the atomisation conditions by changing the geometry of the atomiser. Injecting particles from the side does not create these problems because the particle injection is now independent of the atomisation and both processes can be adjusted separately. Abrasive wear-off of the powder injection nozzles remains a problem but does not have the same immediate impact on the spraying conditions as for the powder injection via the atomising gas.

In all cases one has to take care that the particle injection does not influence the atomisation and particle flight conditions too much. This means that one is limited in choosing the pressures and gas flows of the gas which transports the powder particles.

2.2 Construction of a powder injection device

For the purpose described in section 1 we chose the following components. We used a twin screw feeder for transporting the powders from a reservoir into a mixing chamber. The twin screw feeder was found to transport even damp and strongly agglomerating powders in a fairly reliable way without compacting the powders too much. Moreover, the twin screw feeder can be operated between 0 and 600 ml per minute which are transport rates in the desired range. An example for the transport characteristics is shown in Fig. 2. Calcium carbonate powder ($\text{CaCO}_3 \cdot 3\text{H}_2\text{O}$) was chosen for this test because this powder had been shown to be difficult to transport due to its high content of moisture. As one sees, the transport characteristics are quite satisfying: the short term fluctuations are less than about $\pm 5\%$, the long term stability of the feeding rate changes less than 10%. The short term fluctuations are expected to be partially averaged out when the powder is dispersed with help of the transport gas.

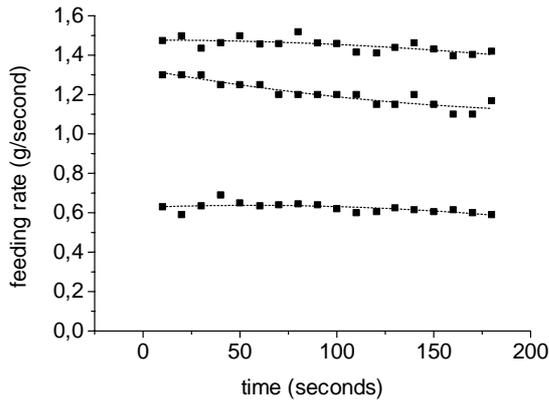


Fig. 2: Transport characteristics of a twin screw feeder operated in three different speeds and transporting CaCO₃.

The twin screw feeder transports the powder into a vertically arranged cylindrical pipe with a conical outlet. The transport gas flows through a nozzle and creates a negative pressure which drags the powder into the gas stream. The negative pressure also causes a gas stream

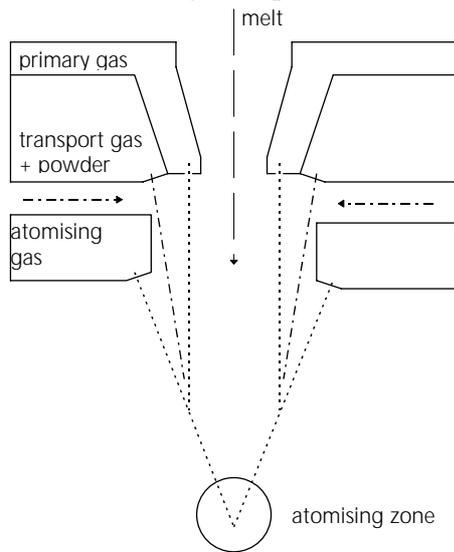


Fig. 4: Injection zone of the powder injection unit: schematical view of the relative orientations of the various gas jets

From the mixing chamber the powder was transported to the actual injection nozzle in the spray chamber by a stream of nitrogen gas. An optimum set-up for dispersing the powder in the gas was found after various experiments and is shown in Fig. 3.

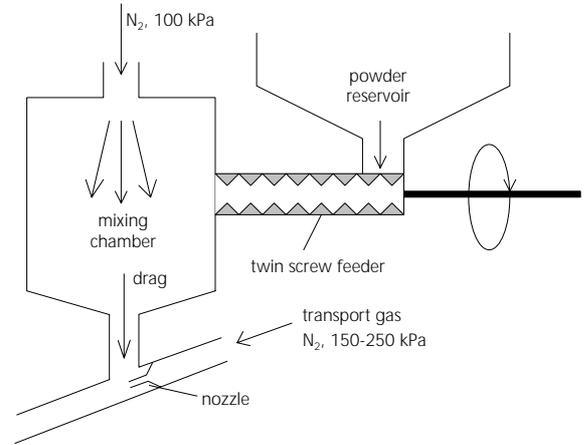


Fig. 3: Schematical view of the powder dispersion unit

through the gas line which connects the upper end of the mixing cylinder which the atomisation chamber. This gas stream helps to disperse the powder which comes out of the twin screw feeder and to break up powder agglomerates. This way the powder which is fed into the mixing chamber is transported to the injection zone continuously and at a constant rate.

We wanted to maintain the advantage of version c) in Fig. 1, namely the good contact of powders and molten metal when the powder is injected into the spray cone directly into the atomisation zone but wanted to have the freedom to adjust the transport gas independently of the atomisation gas. Therefore we choose to install a special nozzle for the powder saturated transport gas near the atomisation zone. According to this construction the powder is injected into the region between the atomising gas and the primary gas stream, which serves to stabilise the atomisation process. Fig. 4 shows schematically how the various gas jets are orientated. One sees that the powder particles are dragged into the space between the atomisation stream and the primary gas stream and are directly fed into the atomisation zone this way.

3. Results of powder injection experiments

The powder injection device was tested by injecting various powders into the spray cone. Among the powders used aluminium turned out to be most suitable because the aluminium content could be easily measured in the deposit by energy dispersive X-ray analysis and because aluminium powders in the gas stream could also be observed visually very well.

3.1 Qualitative and visually supported tests under "dry" conditions

In a first step aluminium powders were injected into the spray chamber while the metal atomisation was not operating („dry“ conditions). All gas streams (atomising gas, primary gas and powder transport gas) were turned on. The gas injection zone around the various nozzles was observed visually and by means of a video camera when the powder transport was turned on. With a certain delay the powder started to be injected and formed a well defined gas/powder stream which lead directly into the atomisation zone where it interfered with the atomising gas (Fig. 5). After about 10 seconds the powder stream appeared to be fairly constant with only small pulsations visible. Slow motion views of the video recording did not reveal any strongly inhomogeneous regions. The appearance of the powder jet in Fig. 6 suggests, that most of the powder is focused into the atomisation zone and very little powder gets scattered into regions outside. Therefore, it can be expected that most of the powder reacts with the molten metal.

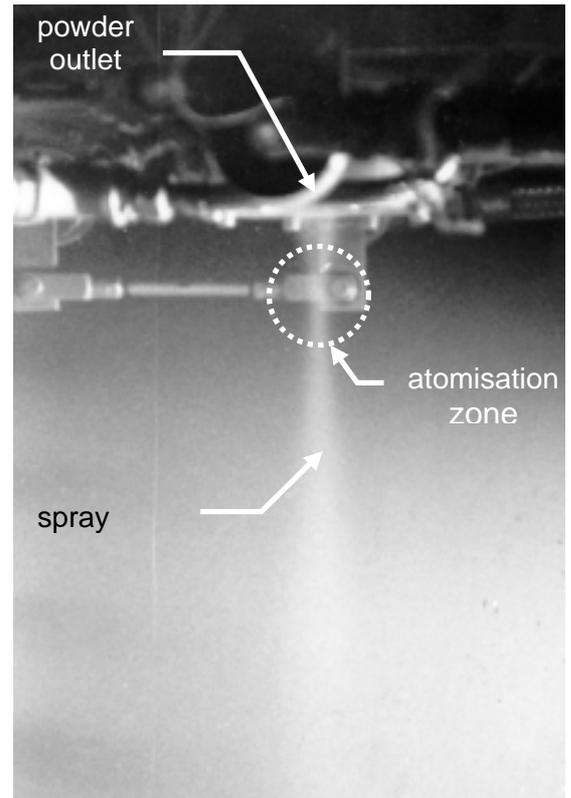


Fig. 5: Optical view of the powder/gas jet.

3.2 Tests with metal atomisation

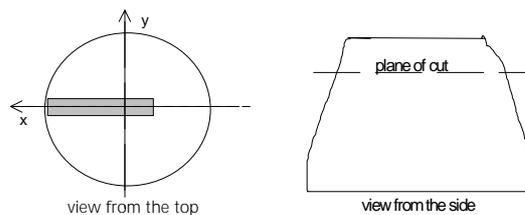
In a next step powder was injected in the normal operation mode including metal atomisation. The atomisation was first started while the powder injection gas still remained turned off. Then, under stationary spray conditions, the powder transport gas was turned on and the atomisation zone was observed visually and with help of a video camera. No changes of the spray cone could be observed visually and by use of the slow motion of the video tape.

Various powder injection experiments were performed with aluminium powder. The spray was compacted on a rotating deposit with 30 degrees inclination with respect to the horizontal line. The parameters varied were:

- powder injection rate: 50, 100, 200 g/min.
- pressure of the transport gas (150 and 250 kPa)

In all cases deposits of about 20 kg could be obtained. The deposits were cut into two horizontal planes and various radial strips of an area 80x20 mm were prepared (see upper part of Fig. 6)

The aluminium content of one such strip is shown in Fig. 6. An amount of 0.2% has been subtracted to account for the aluminium content in the starting material. One sees that the average aluminium content is about 0.8% and that distribution of the aluminium is very uniform over the dimensions of the deposit. Analysis of other strips yields very similar curves. Thus it can be concluded that using the powder injection device described a homogeneous particle distribution can be achieved.



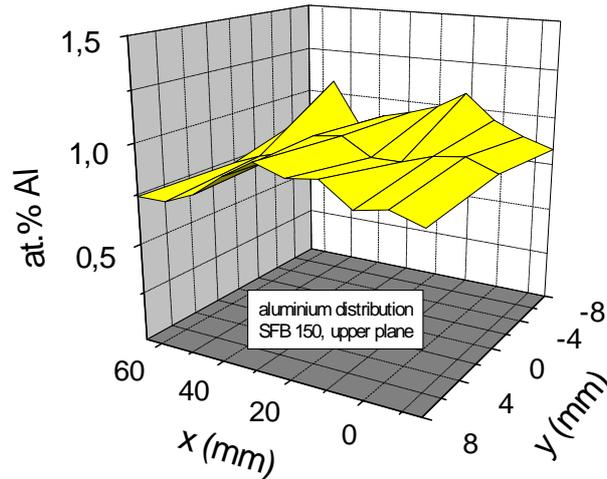


Fig.6 : Aluminium distribution one part of a deposit containing aluminium

From the total amount of injected aluminium powder and the aluminium content of the deposit, the fraction of aluminium which was actually incorporated into the steel deposit was determined. The fraction is about 70%, that means, the overspray losses are about 30%.

4. Formation of Porosity

For creating porosity in a spray formed deposit, gas releasing substances have to be injected. There are two possibilities to create gas:

- to use a substance which dissociates thermally. Examples for this are metal hydrides and carbonates. One can use CaH_2 to create hydrogen gas according to the reaction $\text{CaH}_2 \rightarrow \text{Ca} + \text{H}_2$ or BaCO_3 which forms CO_2 according to the formula: $\text{BaCO}_3 \rightarrow \text{BaO} + \text{CO}_2$. The gas releasing agents have to be chosen by trying to find ideal decomposition characteristics. The decomposition temperature must not be too high because then the amount of released gas is too low and not too low to prevent premature decomposition while the particles are still flying.
- to inject a substance which reacts with an element contained in the liquid steel and forms gas this way. Using silicon or manganese oxide powders and a carbon rich steel one obtains large quantities of CO_2 : $\text{SiO}_2 + \text{C} \rightarrow \text{Si} + \text{CO}_2$, or $\text{MnO}_2 + \text{C} \rightarrow \text{Mn} + \text{CO}_2$.

Fig. 7 shows one selected result based on manganese oxide as a gas releasing substance. Manganese oxide was injected into a carbon steel containing 1.05% C at a rate of 100g/min.. The MnO_2 particles were rather coarse (150 μm) and could be injected without any problems. The strong gas formation could already be noticed by visual observation of the deposit where a strong bubbling could be seen. One sees that the resulting porosity is quite strong and not very homogeneous. Naturally the highest degree of porosity is found near the big central cavity. Towards the edges of the sample the porosity reduces quickly. The porosity level is in the range of 40 to 56% in the region below the central cavity. Hence, the goal of making porous „foams“, i.e. creating more than 50% porosity, seems achievable this way. Of course, a more homogeneous distribution of pores is indispensable. One of the reasons for the unfavourable pore distribution is the low viscosity of the melt. In current experiments it is tried to solve this problem by adding viscosity enhancing substances.

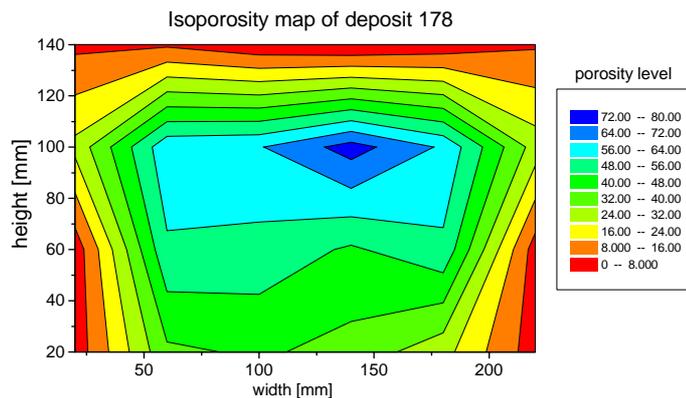
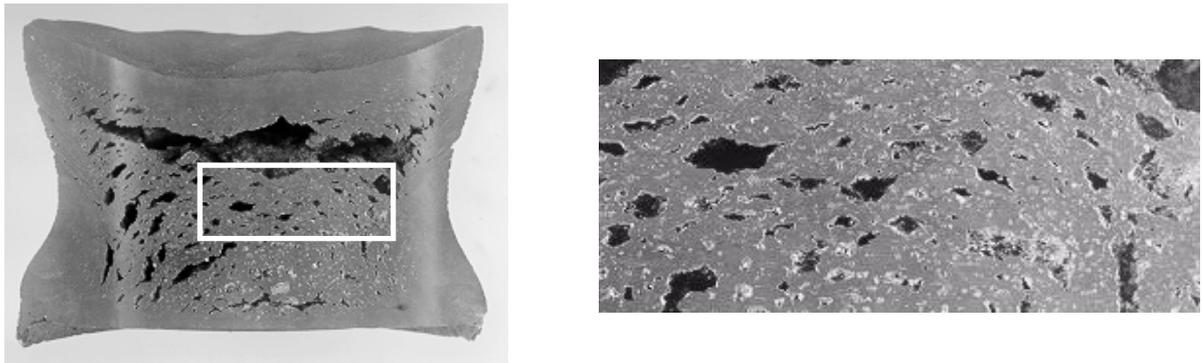


Fig. 7: Porous steel deposit produced by injecting MnO_2 into a steel with 1.05% carbon content. Upper part: micrographs at two different magnifications, lower part: porosity level of the sample.

5. Summary

We presented a novel powder injection device for incorporating metal and ceramic powders into metallic deposits in spray forming. A combination of a twin screw feeder, a pneumatic transport system using a nitrogen transport gas stream and a specially designed gas nozzle which injects the powder into the space near the atomisation zone, was proved to yield a constant transport rate. Analysis of steel deposits after injecting aluminium powder showed that a homogeneous distribution of the powders in the steel matrix can be achieved. Injection of gas releasing substances created highly porous deposits.

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References

- [1] E.J. Lavernia, N.J. Grant, *Mat.Sci.Eng.* **98**, 381, (1988)
- [2] A.R.E. Singer: *Mat. Sci. Eng.* **A135**, 13, (1991)
- [3] A. Lawley, D. Apelian: *Powder Met.* **37**, 123, (1994)
- [4] A. Lawley, R. Knight, A. Zavaliangos: *European Conference on Advanced PM Materials (PM'95)*, Birmingham, UK, 23.-25.10.1995, p. 158
- [5] P. Kelly, C.R. Wong, A.L. Moran, *Int. J. Powder Met.* **29**, 161, (1993)
- [6] H.-D. Kunze, J. Banhart: *Report of the research programme SFB 372 (Bremen, 1994-1997)*, p.321
- [7] J. Banhart, J. Baumeister, M. Weber: *European Conference on Advanced PM Materials (PM'95)*, Birmingham,UK, 23.-25.10.1995, p. 201