CASTING FLUIDITY OF MELT—PARTICLE SLURRY IN CAST COMPOSITES

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
METALLURGICAL ENGINEERING
(with specialization in Industrial Metallurgy)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the dissertation entitled **"CASTING FLUIDITY OF MELT-PARTICLE SLURRY IN CAST COMPOSITES"**, in partial fulfillment of the requirement for the award of the degree of **MASTER OF ENGINEERING** in Metallurgical Engineering with spcialization in **INDUSTRIAL** METALLURGY, is an authentic record of my own work carried out for a period of about six month from Oct. 1993 to Feb. 1994 under the guidance of **Dr. S. RAY AND Dr. V. AGARWALA.** The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

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This is certified that the above statement made by the candidate is correct to the best of knowledge.

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CONTENTS

ABSTRACT

Casting of melt-particle slurry or suspension into composite components often creates a problem of particle segregation due to settling under dynamic conditions of flow in the mould channels. The present study has aimed to devise a set-up for investigating this phenomenon. A slurry of 10 wt% of - 325 mesh size alumina particles in molten aluminium is sucked into a channel of pipes under different levels of vacuum resulting in different flow velocities of the slurry in the pipe. The flow velocity has been measured with the help of two thermocouples by noting the time interval when the slurry reaches two predetermined points. The microstructures of the slurry solidified in the pipe while under flow at velocities of 28 cm/sec. and 40 cm/sec. have been investigated at different flow distances. It has been observed that at higher flow velocities larger clusters of particles are sucked into the pipe as compared to that at lower flow velocities. Settling during flow has resulted in an increase in particle content at the bottom of the pipe but a decrease in particle content at the top in the pipe with increasing distance of flow. It has been attributed to longer settling time available in the slurry segment which flows a longer distance. However, the particle content in the middle of the pipe is relatively uniform. It is evident that the flow velocities used in the present investigation is not sufficient to overcome the effect of particle settling which is enhanced in larger particle clusters sucked at higher flow velocities.

CHAPTER - 1

INTRODUCTION

Metals and alloys containing dispersions of non-metallic particles are generally referred to as metal matrix particle composites. Such composites can be made in the cast form by dispersion of non-metallic particles in a vortex created by stirring the liquid melt, and subsequently casting the melt containing the suspended particles into suitable moulds. Suspension of solid particles in liquids are known to increase viscosity and decrease fluidity and they could impair the castability of these composites. Some researchers have shown that fluidity of alloys containing Al_2O_3 particles decreases with decreasing amount of Al_2O_3 particles in the melt.

Cast aluminium

Cast aluminium matrix particle composites have been developed and it is observed that they possess adequate mechanical properties. However, there is very little information available regarding the fluidity of melts containing dispersion of different particles such as Al_2O_3, SiC etc. Characterization of fluidity of Al-Al_2O_3 particle composites is important since it will determine the kinds of castings that can be made out of these composites. The viscosity of the alloy melt with suspended Al_2O_3 particles will affect the rheocasting behaviour and die casting behaviour of these suspension.

The casting characteristics of a melt-particle slurry or suspension has certain distinctive aspects over that for

monolithic alloys. The distribution of particles in the castings will have to be satisfactory to obtain reasonably uniform properties. Settling of particles during flow of slurry in mould channels can result in particle segregation in the castings. The objective of the present investigation is to study particle distribution of Al_2O_3 particles, in the channels cast by sucking the slurry at different speeds. Settling of particles in the slurry during the flow and solidification in the pipe is the primary target of this study.

CHAPTER - 2

LITERATURE REVIEW

2.1 SYNTHESIS OF CAST COMPOSITES :

Production of metal matrix composites (MMCs) by casting techniques is one of the low cost route for manufacturing materials for a variety of engineering applications. Continuous or discontinuous reinforcements i.e. fibres, whiskers and particles, that are presently used to reinforce MMCs include : alumina, silicon Carbide, titanium carbide, mica, graphite, etc. Important factors of considerations for manufacturing of metal matrix - ceramic dispersed composites are : bonding, distribution of dispersoids, melting and metal-dispersoids interface characteristics. Metal matrix - ceramic particle reinforced composite materials are produced primarily by powder metallurgy and by casting methods. Liquid fabrication techniques of MMCs has advantage over other techniques (i.e. powder metallurgy). Some of these advantages are : ease of production of components with complex shapes, flexibility and lower cost [1].

USA and Australia, which are two largest and important producers of aluminium, have started regular production of cast composite ingots which are to be melted, in the foundries of user industries, and cast into various components. A number of investigations are being carried out to identify the problems which are associated with remelting and casting of composites and to investigate the remedies in the form of guidelines as they exist for standard foundry alloys.

In foundries, the melts are generally held in ladles during the mass production of cast components and settling of ceramic particles in molten matrix may pose a serious problem. In the case of metal matrix composites like aluminium-alumina particle composites, it is also important that a uniform distribution of alumina (Al_2O_3) particles is obtained throughout the cross-section, and along the length of the casting. Oxide films in the melt may also interfere with distribution and settling behaviour of Al_2O_3 particles. Production of metal matrix composites with complex shape and thin walled castings requires a profound and intimate knowledge of "fluidity". Fluidity is defined by the ability of a molten metal or alloy to fill very narrow spaces or channels. The test that is used to determine the fluidity of molten alloys is called fluidity test. Different types of test are used to determine the fluidity of molten alloys. One of the common test mould used for fluidity test is casting fluidity mould. The test is conducted in sand, metal or graphite. The casting fluidity test in metal employs a metal mould with strip cavity of various thicknesses which measures the ability of molten metal to fill narrow sections.

2.2 CASTING OF COMPONENTS :

In this section different methods for fabrication of components are discussed briefly.

DISPERSION PROCESSES

(i) In stircasting, the alloy is in a fully molten state when the wetting agent and the particles are stirred into it. The

wetting agent will not be necessary when the particles are naturally wetted by the alloy or have a wettable coating. The process of particle transfer to molten alloy has been analyzed and wetting angle plays a critical role. In compocasting, the alloy is in semi-solid state when the particles are stirred into it and in all other respects both the processes-stircasting and compocasting, are identical [2].

The process variables for stircasting and compocasting are (i) position of stirrer, (ii) size of stirrer, and, (iii) speed of stirrer. If temperature of melt is taken as a continuous variable across the liquidus both the techniques can be discussed together. It is possible to stir liquid or semi-solid alloy without a stirrer and recently, Amax Inc. has developed a process involving mixing of particulate reinforcements into molten alloy under conditions of magnetohydrodynamic stirring, followed by direct chill casting of melt-particle slurry.

Dow Laboratories have used a single screw extruder (used conventionally for processing polymer products) for synthesizing magnesium alloy base composites. Magnesium alloy pellets and reinforcing powders are fed through the feed hopper and the screw acts both as a mixer and a viscosity pump. The slurry of alloy and particle at 580^{o}C is fed to the die in the exit end of the barrel for casting net shape composite products. The process has also been extended to synthesis of aluminum alloy base composites. The process variables are rotational speed of the screw and

temperature profile inside the barrel.

(ii) Squeeze Casting :

In squeeze casting a preform or a bed of dispersoids is impregnated by molten alloy under application hydraulic pressure. The die and preform are initially preheated in order to avoid premature chilling of melt. The plunger is also preheated. Preform fits fairly tight into die cavity to reduce danger of premature melt penetration into periphery, and trapping pockets of air within preform or bed of dispersoids. For each composite system, there is a critical preheating temperature of particles, lower than the liquidus temperature of penetrating alloy. If preheating temperature exceeds the liquidus temperature, there will be complete penetration but molten alloy under high pressure, will leak and splash out of vents and clearances between plunger and die. The important process variables affecting quality of squeeze cast composite are (a) die preheat temperature, (b) pressure applied, and (c) packing density of the particles in preform or bed. Schematic diagram has been shown in Fig. 1.

(iii) Pressure Infiltration :

In pressure infiltration hydraulic pressure of squeeze casting is replaced by gas pressure. The main components are pressure vessel containing melt in a crucible placed inside a furnace, and a pipe immersed in liquid metal at one end, while the other end is vented to either a neutral atmosphere or vacuum. A preform or a bed of particles is placed in the pipe blocking the

passage. These particles in the pipe are either preheated by immersion in liquid metal or by a separate heater around the seament of pipe containing preform or bed. The process variables in pressure infiltration are the same as those in squeeze casting. If the pressure vessel is not pressurized and the end of the pipe is not vented to neutral atmosphere, but connected to a vacuum line, liquid metal will infiltrate due to vacuum and the process is called vacuum casting.

(iv) Lanxide Process :

In Lanxide process, a bed of dispersoid or preform is placed on an alloy ingot and the assembly is heated to a high temperature above the liquidus temperature of alloy under a controlled atmosphere like that of nitrogen. The alloy should have such composition that on melting, it wets dispersoid particles and infiltrate into the bed or preform without application of pressure. The resulting composite may be made to net or near net shape by using suitable preform of dispersoid. The process variables in this process are (a) infiltration temperature and (b) particle size, apart from composition of alloy and nature of atmosphere. Here, infiltration takes place almost spontaneously and so, wettability of dispersoids by alloy is extremely important. Schematic diagram has been shown in Fig. 2

(v) Osprey Process :

In Osprey [8,18] process, a molten metal stream is fragmented by means of a high speed cold inert gas jet passing through a

spray gun and dispersoid powders are simultaneously injected. A stream of molten droplets and dispersoid powders is directed towards a collector substrate where droplets recombine and solidify to form a high density deposit. Dispersoid particles may combine with droplets during flight but most particles are generally co-deposited. particle spraying can be independently controlled and may be directed to selected areas. The process depends critically on the ability to control enthalpy of droplets in impinging spray. A droplet should be partially solid when it reaches the substrate. If properly controlled, the process can result in solid deposits in different net shapes of tubes, round billets, strips or clad products. The grain size of resulting composite is relatively uniform and presence of particles during solidification of droplets, refines the matrix microstructure. It has also been claimed that there is much less surface reaction or degradation of dispersoid because cold powders are injected. This process is capable of achieving a high rate of production and the deposited product can be directly used in hot forming like forging, rolling or extrusion. The process variables are : (a) temperature of alloy, (b) speed of gas jet, and (c) temperature of substrate. Schematic diagram has been shown in Fig. 3.

(vi) Rapid Solidification Processing :

In rapid solidification processing of composites, a jet of liquid alloy-particle slurry impinges under pressure on a water cooled copper wheel, and the resulting flake powders are collected. The flakes are of thickness 40-60 μm, length 6-8 mm

and width 0.5 to 0.7 mm. Two critical processing parameters are speed of the quenching copper wheel and amount of material impinging on this wheel. If the wheel turns too fast, slurry will not attach to wheel long enough to produce powder. In the other hand, if the wheel is too slow, flakes will be too thick and unacceptable for subsequent processing. The power is put into cans and consolidated into billet and/or extruded to form a dense composite with higher yield strength, ultimate tensile strength and ductility. Schematic diagram has been shown in Fig. 4.

(vii) In-situ Production of Dispersoids :

Compound dispersoids like TiC, TiB_2, TiN and NbB_2 can be produced in an alloy matrix by allowing components to come in contact and react during high temperature processing in liquid or solid state. The matrix alloy may include aluminum or copper base alloys or intermetallic compounds like aluminides. One of the reacting constituent may remain in solution in molten matrix alloy and the other constituent may be added as fine powders. A typical example is formation of TiC reinforced composite by addition of titanium or ferrotitanium to molten cast iron. It is also possible to use a gaseous reacting constituent like acetylene or methane bubbling in a molten alloy bath containing a carbide former and chemical reaction may result in fine dispersion of carbide. The reinforcements can be of various shapes and sizes depending on processing conditions.

2.2.1 Gating and Risering

After melting, the metal is poured or injected into the mould cavity. We shall now discuss the difficulties faced in doing this and explain how these can be overcome by using an appropriate gating design. A good gating design ensures distribution of the metal in the mould cavity at a proper rate without excessive temperature loss, turbulence, and entrapping gases and slags.

If the liquid metal is poured very slowly, then the time taken to fill up the mould is rather long and the solidification may start even before the mould has been completely filled up. This can be avoided by using too much superheat, but then gas solubility may cause a problem. On the other hand, if the liquid metal impinges on the mould cavity with too high a velocity, the mould surface may be eroded. Thus, a compromise has to be made in arriving at an optimum velocity.

The design of a gating system depends on both the metal and mould compositions. For example, an elaborate gating design is needed to avoid dross (e.g., oxides) in easily oxidized metals of low melting point such as aluminium. For cast iron, however, a short pat for the liquid metal is selected to avoid a high pouring temperature. The gating design for a ceramic mould is quite different from that normally used for a permeable sand mould.

Broadly, gating designs can be classified into three categories, namely, (i) vertical gating, (ii) bottom gating, and (iii) horizontal gating. In vertical gating, the liquid metal is poured vertically to fill the mould with atmospheric pressure at

the base. In bottom gating, on the other hand, the liquid metal is filled in the mould from bottom to top, thus avoiding the splashing and oxidation associated with vertical gating. In the horizontal gating system, additional horizontal portions are introduced for better distribution of the liquid metal with minimum turbulence.

RISERING :

Solidification time depends primarily on the ratio V/A, where V is the volume of the casting and A is the surface area of heat dissipation (i.e., of the casting). This is also to be expected intuitively since the amount of heat content is proportional to volume and the rate of heat dissipation depends on the surface area. This information is utilized when designing a riser to ensure that the riser solidifies after the casting. However, the information on the amount of liquid metal needed from the riser is used only to compensate for the shrinkage that takes place from the pouring temperature till solidification. Depending on the metal, the percentage of this shrinkage varies from 2.5 to 7.5. Thus the use of a large riser volume (to ensure large solidification time) is uneconomical. So, a riser should be designed with the minimum possible volume while maintaining a cooling rate slower than that of the casting.

It may be noted that a casting with a high surface area/volume ratio requires a riser larger than that determined by considering only the cooling rate. To check the adequacy of the riser size for a steel casting, Caine's relationship is normally

used. Caine's relationship, however, is based on the assumption that the cooling rate is linearly proportional to the ratio surface area/volume. A typical risering curve is depicted in Fig. Here, the ordinate of a point on the curve shows the volume ratio and the abscissa the freezing ratio; also, the subscripts c and r refer to the casting and the riser, respectively. For a given casting-riser combination, if the point falls to the right of the curve, the adequacy of the riser is ensured. The equation for a risering curve is of the form [19]

$$x = \frac{a}{y - b} + c,$$

where a is the freezing constant for the metal, b is the contraction ratio from liquid to solid, and c is a constant depending on the different media around the riser and the casting. The value of c is unity if the mould material around the casting and the riser is the same. For steel, the typical values of a = 0.1 and b = 0.03. For Al it is in between two.

2.2.2 FLOW OF SLURRY IN MOULD CHANNELS

Due to settling of dispersoid particles, the number of particles at the bottom side of a mould becomes higher than that in the middle portion or upper side of channel during flow of the slurry. And this settling tendency create problems in obtaining uniform distribution throughout the section. This is due to density difference between the reinforcing particles and matrix

melt. This density difference is the primary cause of segregation of particles.

Theoretical prediction of particle settling can be made using Stoke's law which assumes : (1) spherical particles; (2) complete wetting between the dispersed particles and the melt. Stoke's law estimates the settling rate of a particle by

$$V_p = \frac{d^2(\rho_p - \rho_l)g}{18\mu} \qquad \ldots \quad (1)$$

where,

V_p = Stoke's settling velocity of particle

d = particle diameter

ρ_p = density of the particle

ρ_l = density of liquid

g = gravitational acceleration

μ = viscosity of the melt

When there are several particles present, there is hindered settling due to the presence of other particles. This will reduce the settling velocity compared to what is calculated for individual particles by stoke's law. The hindered settling velocity is given by Richardson and Zaki [3].

$$V_c = V_p(1 - \phi)^n \qquad \ldots \quad (2)$$

where,

V_p = Stoke's settling velocity

ϕ = volume fraction of particles for Re < 0.2

$n = 4.65 + 19.5\ d/D$

and $n = (4.35 + 17.5\ d/D)\ Re^{-0.03}$ for $0.2 < Re < 1$

where, Re = Reynods No. $= \frac{V_p\ d\ \rho_l}{\mu}$

where d = diameter of particle

and D = diameter of vessel containing the slurry.

T.D. West, in 1902 [6], was the earliest investigator to report on the flow characteristics of molten metals cast into sand molds. He poured metal into a horizontal wedge and considered the distance flowed as a measure of fluidity. Ledebure [7], in 1904, Sexton and Primrose [8], in 1911 and Moldenke [9], in 1917, modified the wedge test somewhat.

Ruff [10], ran metal in a long cylindrical channel, and used the length of flow as his measure of fluidity. This test was particularly sensitive to errors in leveling. Evans [11], tried an inverted "U" type of test in which he used several vertical sections of various cross-sectional areas fed from a common channel. The heights to which the metal rose in the various sections were a gage of fluidity.

Fludity Spiral

The familiar fluidity spiral was first tried by Saito and Hayashi [12], in 1991; their method simplified handling and leveling problems. Many investigators have improved upon this spiral type test; the two best known modifications being those of Saeger and Krytnitsky [13], for cast iron, and of Taylor, Rominski and Briggs for steel. These spirals are now accepted in America as standards for determining fluidity of ferrous metals.

Eastwood and Kempf [14], and later Sicha and Boehm [15], developed a spiral casting of flat cross-section for studying fluidity of aluminum and its alloys. Only a limited amount of experimental work has been done with this fluidity test, but results to date indicate it is not sufficiently reproducible for research and development work. A "star" type fluidity test piece has been developed by Kondic. It, too, is a relatively recent development which must yet stand the test of time.

A new approach in fluidity testing was developed by Ragone, Adams and Taylor [16]. They developed a "vacuum fluidity test" in which the liquid metal was drawn into a pyrex glass tube by means of a vacuum. Variables of this test were determined experimentally and analytically using low melting point alloys. Later investigators have employed this method in precise determinations of the fluidity of magnesium and its alloys, and of aluminum alloys.

Several excellent, comprehensive bibliographies of the history of fluidity testing have been prepared; the reader is referred to these for more complete coverage of the subject.

In 1939, Eastwood and Kempf developed the fluidity spiral of flat cross-section described above. Cross-section of the channel was 13/4 in, wide by 1/16 in, trhick. A simple 3/4 in, diameter downsprue was used with an overflow pouring basin. Sicha and Boehm [15], later modified the design by adding a "well" at the bottom of the sprue and adding a piece of tinfoil to serve as a temporary "dam," thereby reducing the influence of any variation

in pouring. While these modifications were said to result in improved uniformity of experimental runs, nonetheless, fluidity spiral weights for duplicate runs varied by as much as 15 grams, in an average total spiral weight of only grams.

Vacuum Fluidity Test

Utilizing the "vacuum fluidity test," Ragone and Floreen [17], investigated the fluidity of a series of aluminum-copper alloys, and aluminum-alumina alloys. Both alloys were investigated in the region of 0 to 33 per cent solute. Results obtained for the aluminum-copper system were qualitatively similar to those obtained by Courty [16], with his quite different fluidity test. In the work of Ragone and Floreen, fluidity was found to vary inversely with solidification range; solidification range was calculated from nonequilibrium considerations in the manner used by Niesse, Flemings and Taylor [18], in their study of fluidity in alloys.

SAND MOLD FLUIDITY TEST

The "vacuum fluidity test" wherein metal is drawn out of a crucible directly into a glass (or metal) fluidity channel has been found to be ideal for studies of the effect of solidification variables on fluidity. In addition, when glass tubes are used, motion picture photography can be utilized to follows the progress of metal during the test. The major disadvantage of the test, however, is that it does not readily permit study of the effect of mold or mold-metal variables on fluidity. For example, study of the effects of sand grain size, moisture content or mold coatings

on fluidity requires the use of a more standard sand mold test. In addition to being able to measure effects of mold and mold-metal variables, a reproducibile sand mold fluidity test would be expected to closely relate to actual conditions of casting.

After carefully evaluating the various test pieces developed to date it was decided no single one was simple enough for extensive testing and also for giving test results accurate enough for laboratory investigation. Accordingly, it was decided to develop a new type test which would be simple and easy to use, and would also :

1) Afford precise control over metallostatic "head," and permit this pressure head to be reached before any metal entered the fluidity spiral.

2) Provide control over metal turbulence as the metal entered the spiral.

3) Filter any dross or other foreign materials from the metal before the metal entered the fluidity spiral and do so without altering the metal "head."

4) Be of flat cross-section to simulate problems encountered in pouring sand castings of thin section in the foundry.

Melt particle slurry must have sufficient fluidity so that it could reach at different sites properly. Temperature plays an important role for it. Casting fluidity is measured by total length travelled by the semi-solid slurry in the channel before

freezing. Comparison of casting fluidity with increase in temperature for Al A356 base alloy and Al A356 alloy containing 10, 15 and 20 Vol. % Al_2O_3 particles is shown in the Fig. 8. As shown in the figure the casting fluidity of the base alloy increases with increase in temperature. However, the casting fludiity of the base alloy has decreased by addition of 10 vol. % Al_2O_3 particles. The casting fluidly of Al-10 Vol. % Al_2O_3 particles increased with temperature upto 760 ^{o}C. The casting fluidity did not increase significantly when the temperature of the melt was increased above 760^{o}C. The casting fluidity length of Al-15 Vol.% Al_2O_3 composite also increased with temperature. However, the addition of 15 Vol. % Al_2O_3 particles to the melt further decreases fluidity compared to that of the base alloy.

2.3 DEFECTS IN CAST COMPOSITES

When one examines microstructure of cast MMPC, several structural defects are commonly observed in different systems; porosity, particle segregation and interfacial reactions have drawn considerable attention so far. The present section summarizes the efforts to control these defects.

(i) Porosity

The mechanical properties of particulate composites are adversely affected by porosity and this damage has several features quite distinct from those of monolithic metals and alloys. At low porosity, one may consider each pore independent of others as inhomogeneous stress distributions around pores are non-overlapping. The damage to mechanical properties like

ultimate tensile strength (UTS) is a linear function of volume percent of porosity [20]. When porosity increases, there is overlap of inhomogeneous stress distributions around pores and damage becomes a non-linear function of porosity. The influence of shape of the pore may average out and is reflected in the slope of damage-porosity curve represented by

$$\frac{\sigma_u}{\sigma_o} = 1 - \alpha p$$

when σ_u and σ_o are respectively UTS in presence of p vol. % of porosity and without it, and α is characteristic slope termed weakening factor. The above equation is found to be valid in composites over a much larger range of porosity in composites as compared to that in metals and alloys [21]. This has been attributed to screening of inhomogeneous stress field around a pore by the hard particles embedded in matrix, restricting its spatial range. It explains the dependence of weakening factor, α, on particle content in a composite.

Apart from normal casting porosity resulting from dissolved gases or shrinkage, there may be additional porosity contributed by the process. In dispersion processes, molten or semi molten alloy has to be agitated to mix dispersoids. The intimate interaction between molten alloy and environmental gases due to agitation, causes enhanced dissolution of gases. Further, if there is a vortex created by agitation, it may cause suction of air bubbles and dispersoids into molten alloy [22]. The extent of

porosity depends on the state of agitation and it can be reduced by control of relevant process variables.

(ii) Particle Segregation

Particle segregation in cast composites could be over either a microscopic scale or a macroscopic scale. The macrosegregation of particles in a composite is generally inherited from inhomogeneous distribution of particles in melt-particle slurries. In stircasting, agitator imparts energies to slurry in the form of eddies and if the scale of eddies are not small enough, it will not be able to break clusters of particles [23] present. These clusters, if not broken during stirring, will be observed as such in the microstructure of cast ingots.

RAPID SOLIDIFICATION PROCESSING

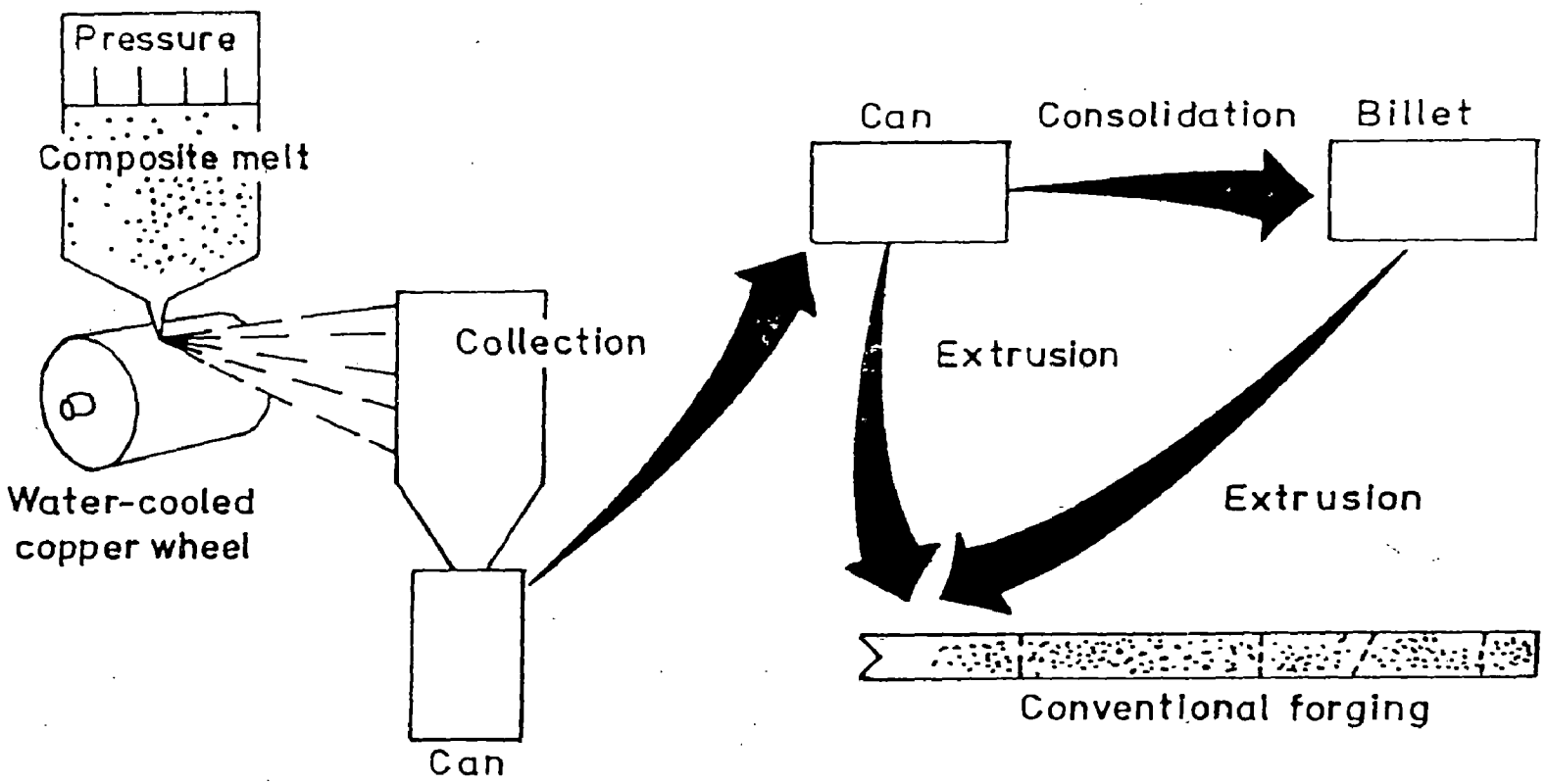


Fig. 4

20(a)

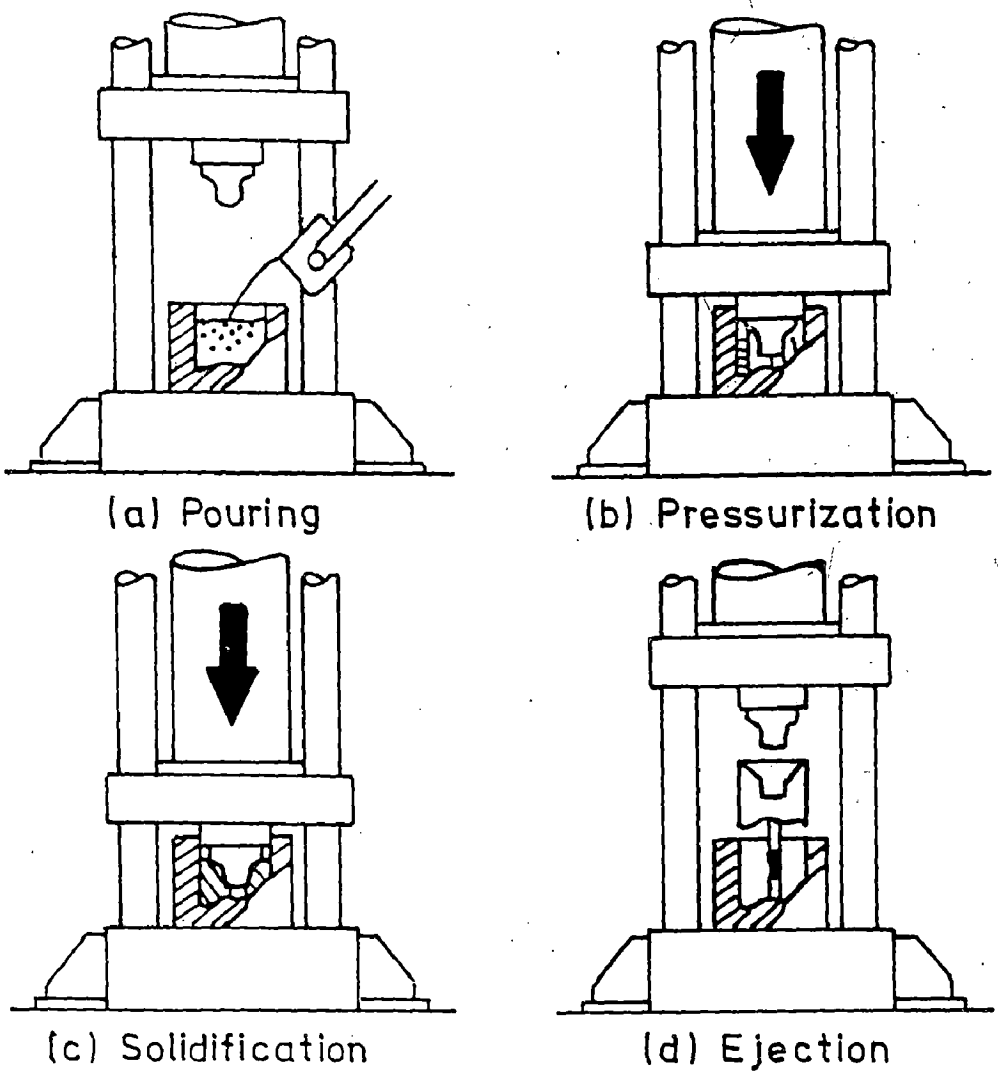


Fig. 1

SQUEEZE CESTING

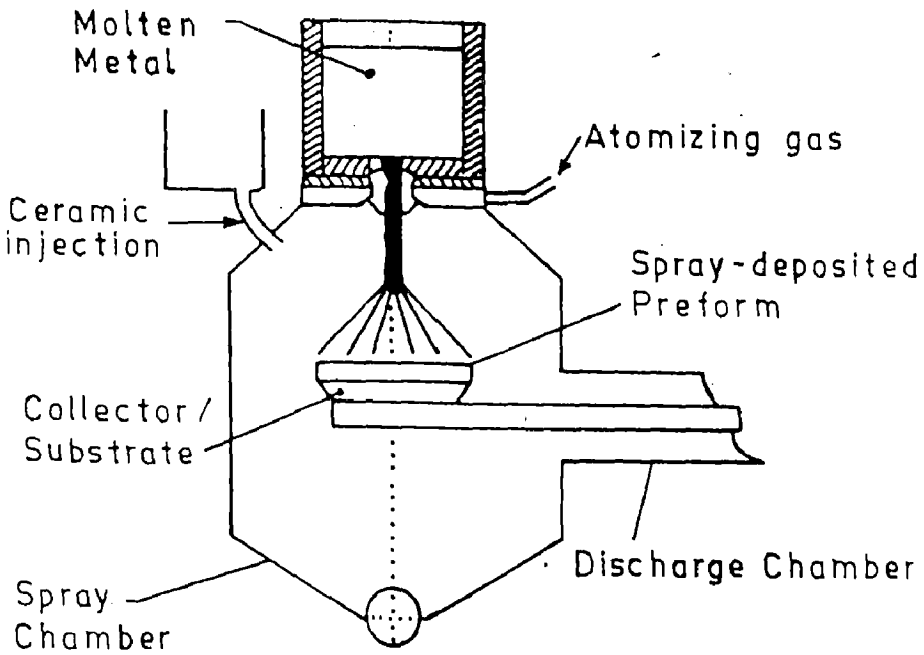


Fig. 3

OSPREY PROCESS

LANXIDE PROCESS

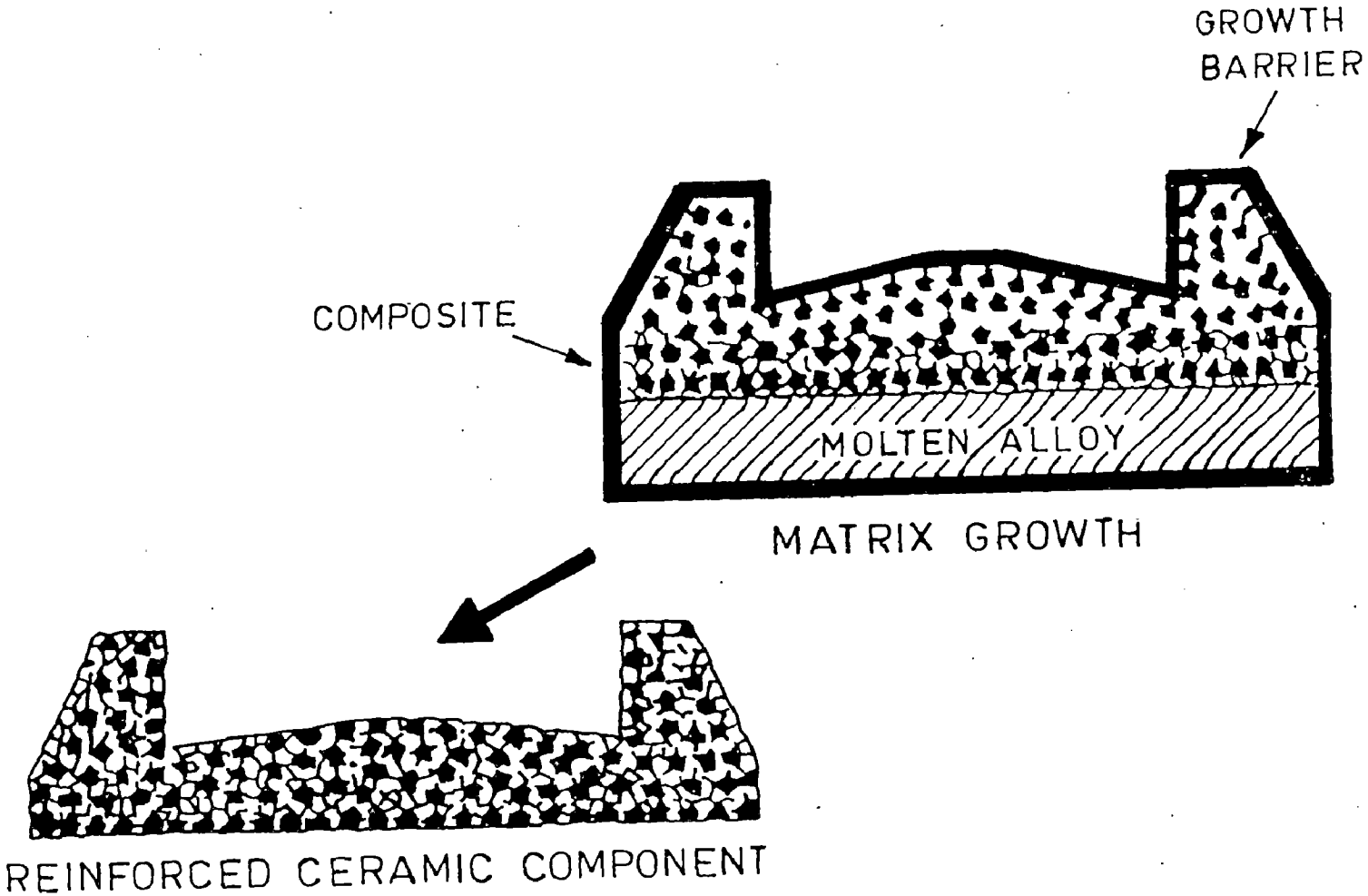
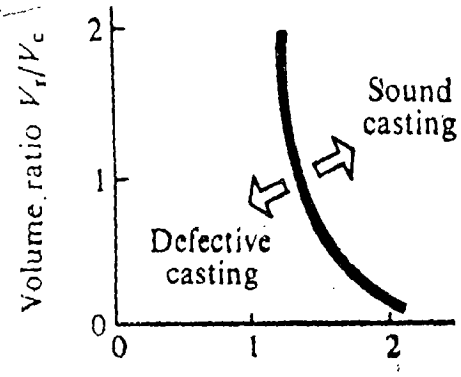


Fig. 2



Proper combinations of volume and freezing ratios.

Fig. 5

CHAPTER - 3

EXPERIMENTAL PROCEDURE

3.1 DESIGN OF SET-UP :

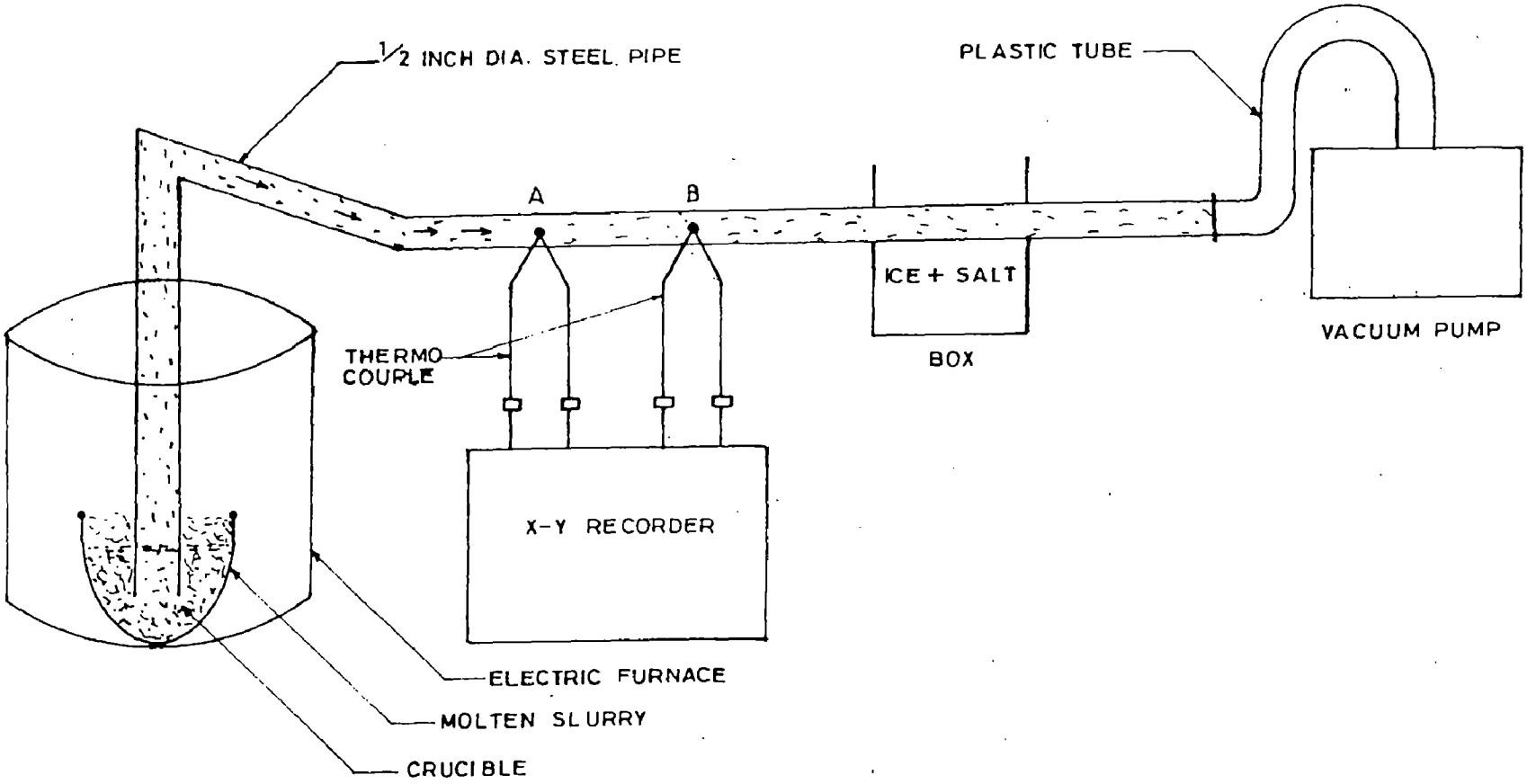
Schematic diagram of experimental set-up has been shown in the Fig. 4.1 A steel pipe of sufficient length (about 6 ft.) is taken. A vertical bend of about 10 inches is provided and the end of this vertical pipe is dipped into the molten metal. From top of the vertical bend a small portion of the pipe is made a little slanted. This is designed to check the return of molten metal into the crucible by the gravity. This slanted length of the pipe is decided according to an outer diameter of the furnaces so that it can rest properly on the top of the furnace and thereby facilitating easy stirring of molten metal to mix Al_2O_3 particles. In the horizontal portion of the pipe two thermocouple probes are attached at sufficient distance. These thermocouple are then connected to X-Y Recorder. After this an ice box is provided which contains ice and salt and is provided to ensure solidification of molten metal so that it can not enter the vacuum pump. This steel pipe is connected to vacuum pump through a plastic pipe. Plastic pipe is used for its flexibility, A vacuum guage is attached to pump to measure pressure. Function of two channel X-Y Recorder in this experiment is to measure the velocity of slurry inside the pipe. As soon as molten metal reaches point A there is a rapid increase in voltage signal and it is drawn on the graph. Again when slurry reaches at point B the second channel marks the response on the graph paper. The distance between two lines indicating rapid increase in voltage signal and the speed of graph

paper provide us the time taken by molten metal to travel distance AB. Distance AB is measured and thus velocity of molten metal is measured.

By creating different level of vacuum different velocity of molten slurry may be obtained.

3.2 FLOW STUDIES

After setting the components of the set-up properly, the temperature of the furnace is raised to 700°C. Small pieces of aluminium of commercial purity weighing 900 gms is put into the crucible. After melting of Al, 4-5 wt% of mg wrapped into Al foil, is is added into the crucible. Aluminium foil is used to so wrap mg so that it may not burn due to its highly inflammable nature.. The oxides formed during the process is removed by skimming. Then, 10 wt% of preheated fine Al_2O_3 particles are added very slowly in molten aluminum and is stirred continuously to mix the particles properly. While stirring is continued, the vertical portion of pipe is lowered and dipped into molten slurry of Al containing Al_2O_3 particles. Vacuum pump is started to suck molten slurry into the pipe and it gete solidified after reaching the box containing iced brine solution. From the response of two thermocouples located at point A and at point B. The time taken by molten slurry in travelling distance AB is noted. Knowing the distance AB the velocity of molten slurry is calculated.



SCHEMATIC DIAGRAM OF EXPERIMENTAL SET-UP

Fig. 4.1

3.3 PARTICLE DISTRIBUTION :

After solidification of molten slurry during flow, the pipe is cut into several pieces at different distance, along its length. These pieces are numbered. Cast Al-Al_2O_3 composite samples are taken out by stripping the pipe off.

Now these samples are polished on emery papers having different sizes of abrasive particles. Subsequently, the samples are polished on polishing wheel with the help of suspension of fine alumina particles in water. Microphotographs are taken at different sites to study particle distribution along the length of the pipe.

The particle contents have been determined at three sites at each section top, middle and bottom by quantitative metallography.

OBSERVATION

V_1 = 40 cm/sec. V_2 = 28 cm/sec.

Sample No.	Distance (cm)	Particle Distribution					
		Top		Middle		Bottom	
		V_1	V_2	V_1	V_2	V_1	V_2
1	2	98	76	137	55	128	60
2	4	98	74	137	55	130	63
3	6	97	62	135	54	132	70
4	8	88	55	133	53	134	80
5	10	85	50	133	50	134	85
6	12	83	42	131	50	135	100
7	14	78	35	130	48	137	110
8	16	77	32	128	43	138	120
9	18	70	23	126	40	140	131
10	20	60	18	124	40	141	135

CHAPTER - 4

RESULTS AND DISCUSSION

The results on the study of particle distribution in the solidified samples of aluminium - alumina slurry flowing section. Page 23(a)

4.1 RESULTS :

Fine alumina particles of 325 mesh size as shown in Fig. 4.1 have been dispersed in molten aluminium. The velocities used under two different levels of section are 28 cm [sec. and 40 cm] sec. respectively.

4.1.1 Study of Microstructures :

Figs 4.2 and 4.3 show the microstructure of the unetched specimen of composites at the bottom of the pipe flowing at velocities of 28 cm/sec. and 40 cm/sec. respectively, at higher velocities it is observed that a relatively large cluster of particles have settled at the bottom as compared to those observed in the samples with a lower flow velocity. But in both these samples the bottom contains larger particle clusters as compared to those in the middle or at the top.

Figs. 4.4 and 4.5 showing the microstructures at the top of the pipe at flow velocities of 28 cm/sec. and 40 cm/sec. respectively, reveals a relatively lower amounts of particles as compared to that at the bottom in the corresponding positions. This is a clear evidence of particle settling during flow. There are relatively few large particle particularly for the sample with a relatively higher flow velocity. In general, there are more fine particles at the top.

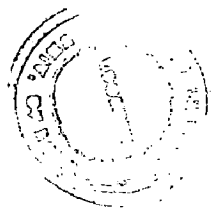
Fig. 4.6 and 4.7 show the microstructures of the samples with flow velocities of 28 cm/sec. and 40 cm/sec. observed in the middle of the pipe at different locations. The sample with larger flow velocities show relatively larger size of particles as compared to those in the sample of lower flow velocity of 28 cm/sec.

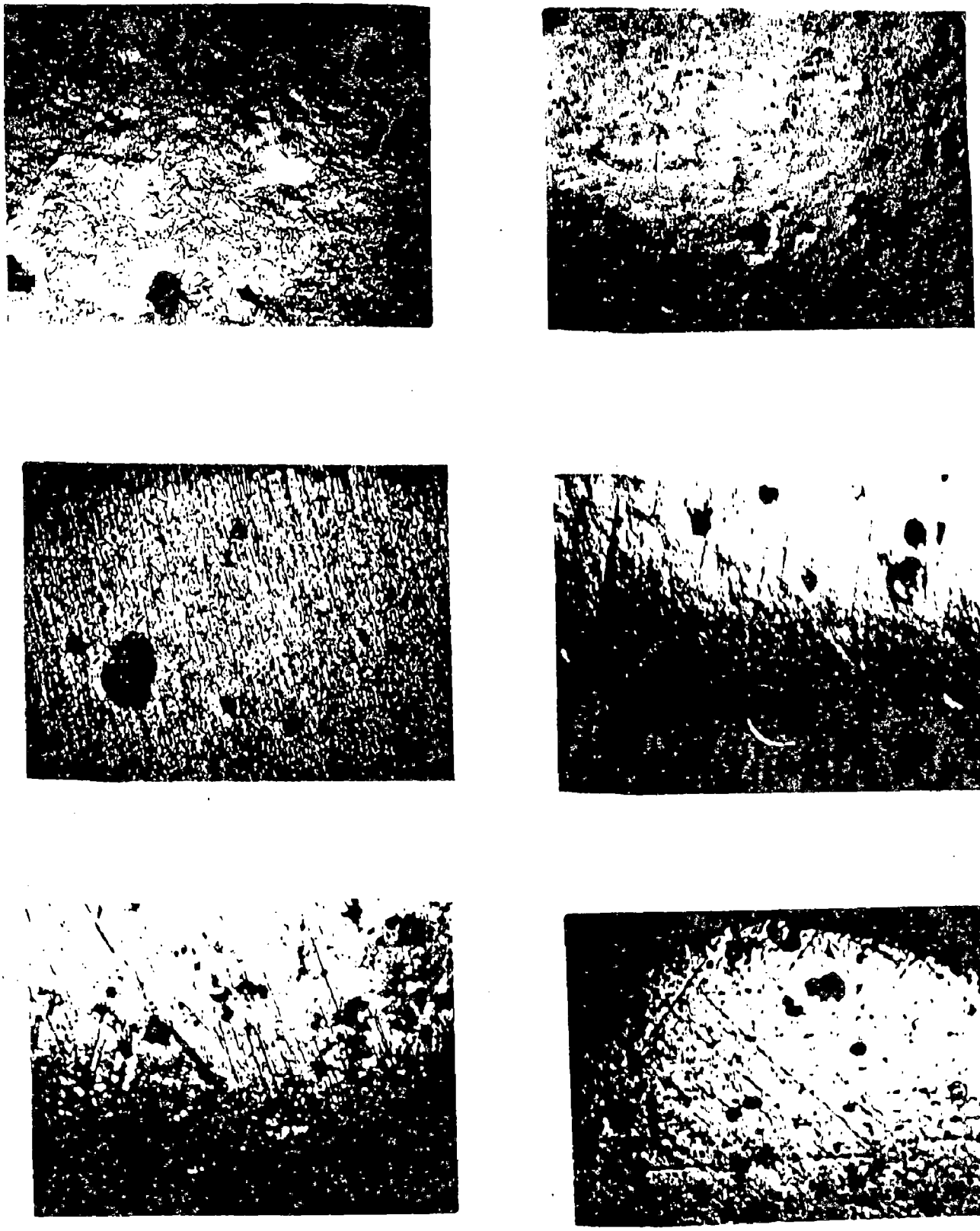
4.1.2 Particle Distribution :

Average number of particles per unit area has been determined by direct counting. For clusters, the average number of particles in the cluster has been estimated on the basis of area of the cluster and the average area of a particle. Fig 4.8 shows the average number of particles. per unit area at the bottom of the pipe at different locations. At higher flow velocity the particle content is fairly uniform but at lower flow velocity the particle content increases with distance of flow. Fig. 4.9 shows that the particles content at the top of the pipe reduces with distance of flow at both the higher and lower flow velocities. The difference in particle content with distance is more maked for lower flow velocity of 28 cm/sec. Fig. 4.10 shows the particle content in the middle of the pipe and it is observed that the particle content is fairly uniform with distance. However, a larger flow velocity results in a higher particle content as compared to these observed in sample with lower flow velocity.

4.2 DISCUSSION :

The presence of relatively larger clusters of particles at the bottom of the pipe when the flow velocity is larger as shown

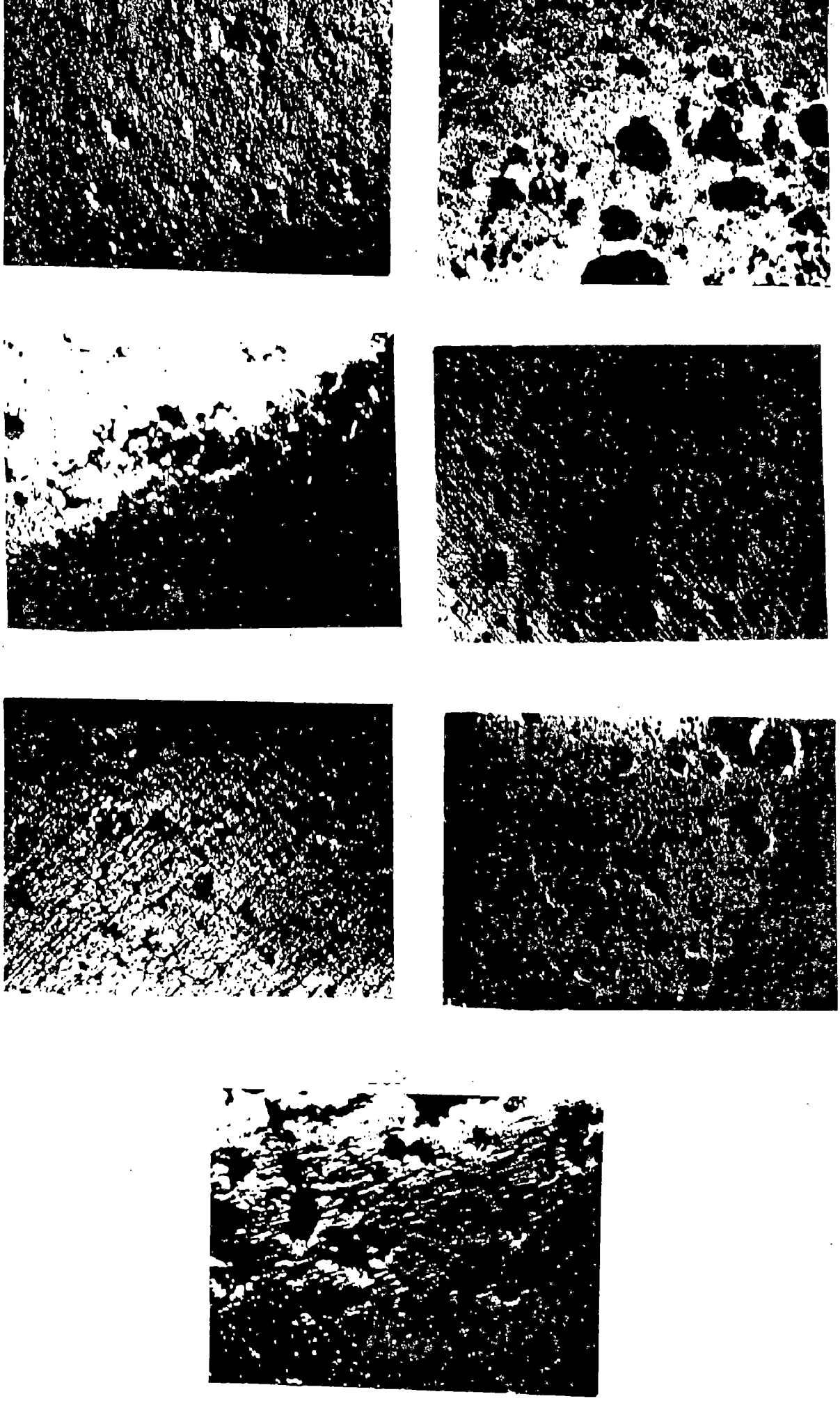




TOP

Velocity = 40 cm/sec

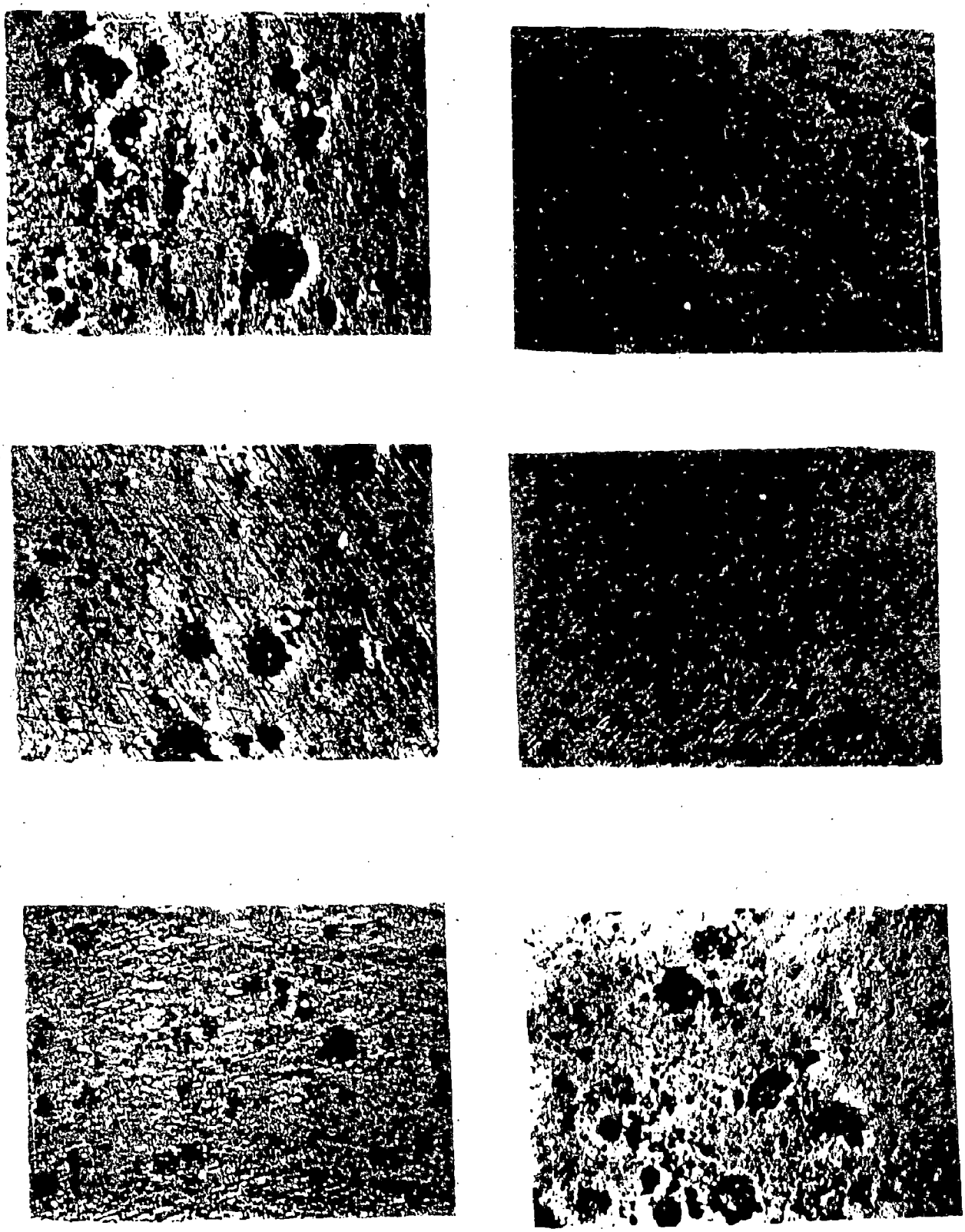
Fig. 4·5



TOP

Velocity = 28 cm/sec

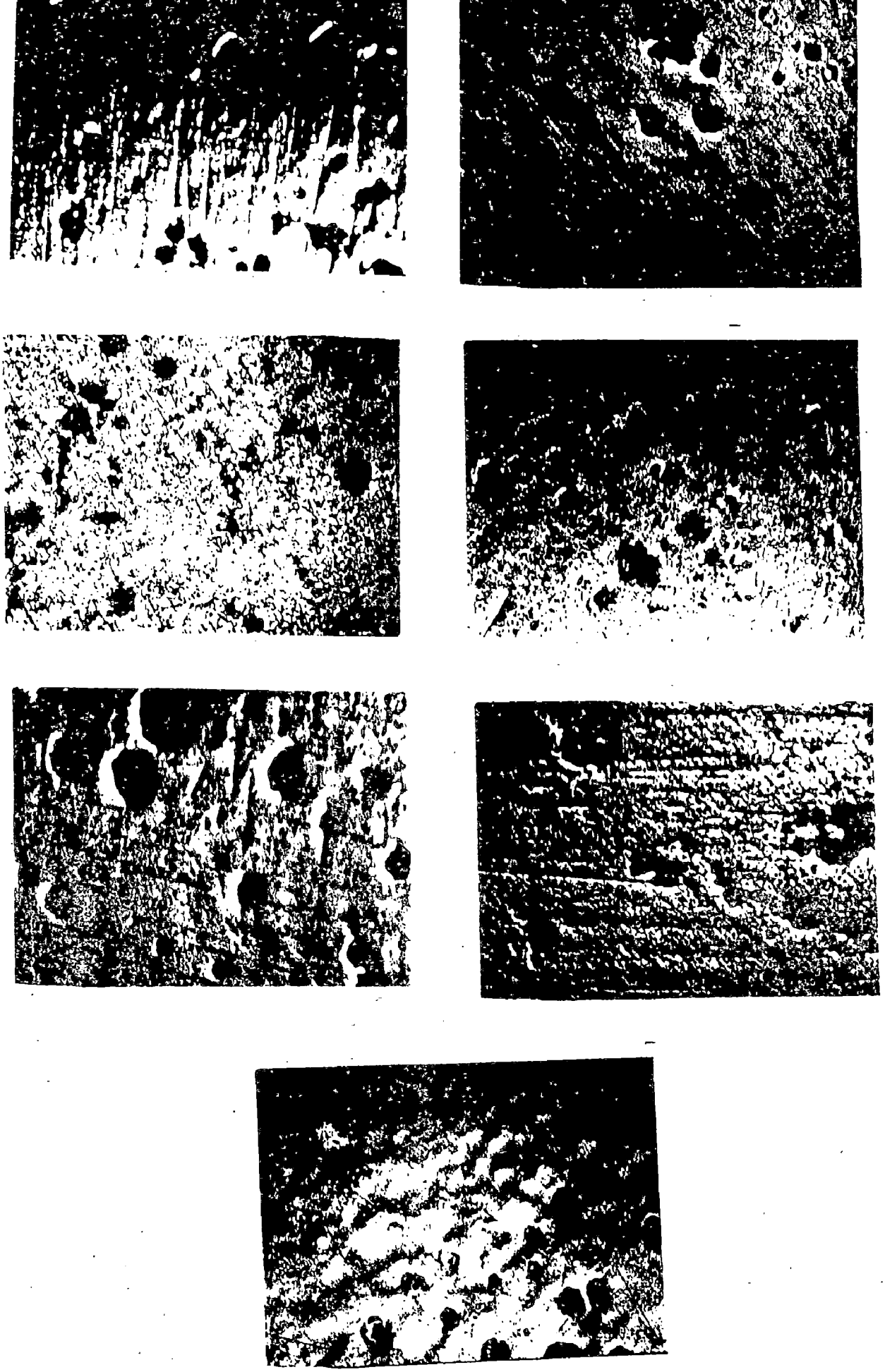
Fig. 4.4



MIDDLE

Velocity = 40 cm/sec

Fig. 4.7



MIDDLE

Velocity = .28 cm/sec

Fig. 4.6

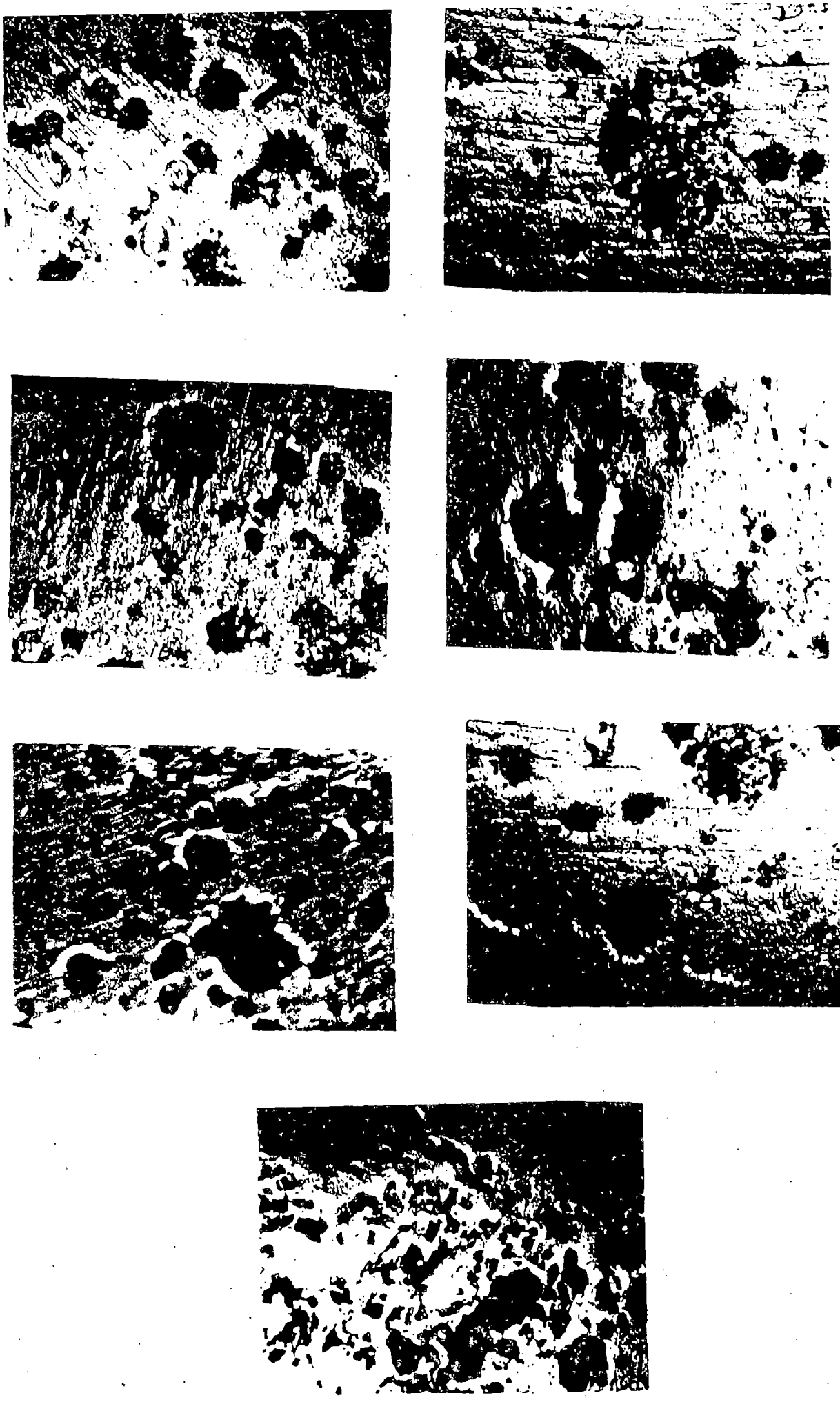
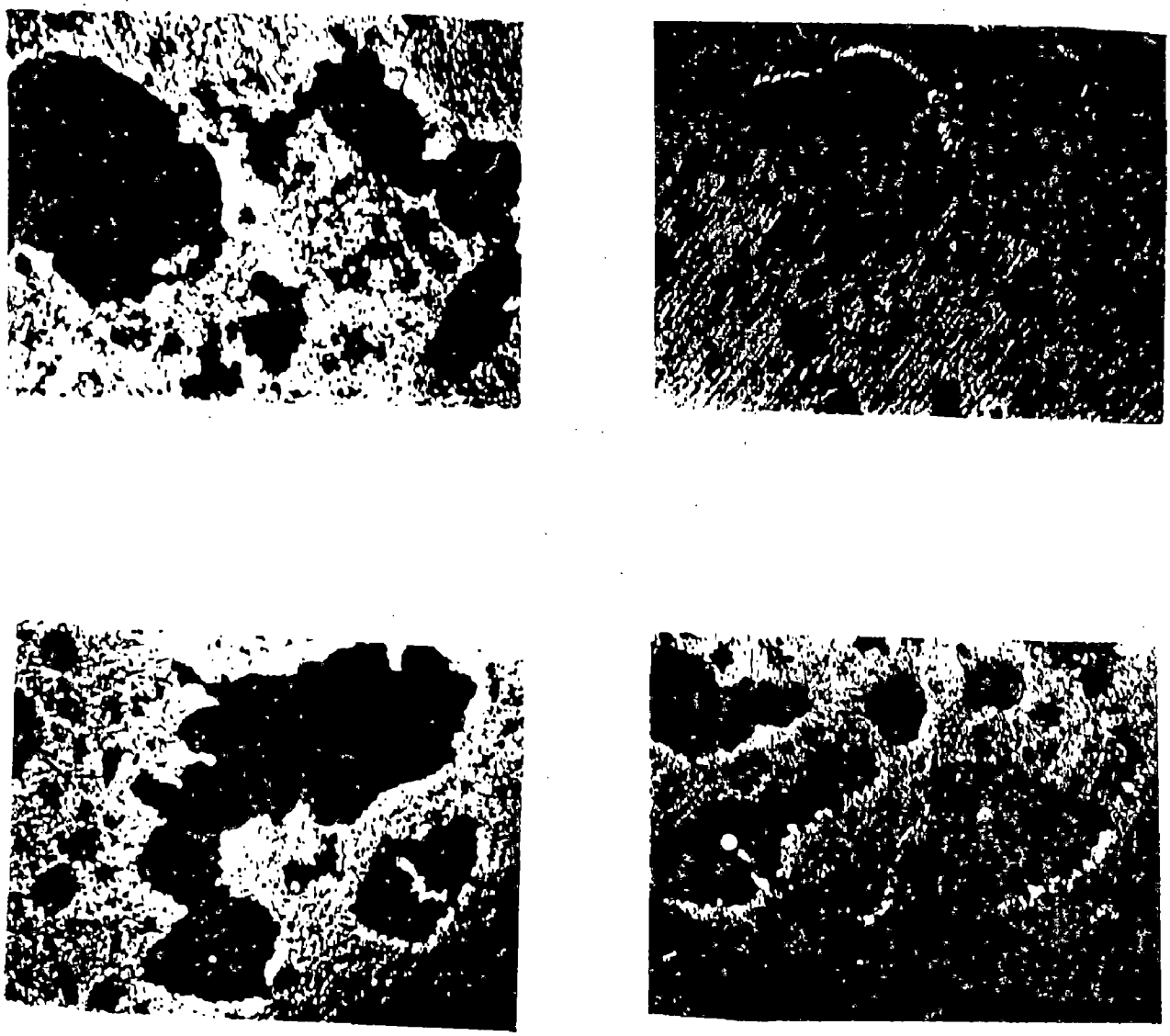


Fig. 4.3

BOTTOM

Velocity = 40 cm/sec



BOTTOM

Velocity = 28 cm/sec

Fig. 4.2

in Fig. 4.3, may be attributed to a higher suction due to which these clusters could be sucked into the pipe. At lower flow velocities, these large size clusters may have been present in the crucible but could be sucked into the pipe as it is evident from Fig. 4.2. But the large clusters settle at the bottom and the extent of settling depends on the time of flow in the horizontal portion of the pipe. The cluster are still being carried by flow and so, particle content at the bottom increases with distance as shown in Fig. 4.8. But at lower flow velocities the cluster size being lower, takes a longer distance to settle and so, there is a larger variation of particle content at the bottom.

Particle settling at the top is evident from a lower particle content at the top of the pipe as shown in Figs. 4.4 and 4.5. The particle content also reduces with the distance of flow as shown in Fig. 4.9. This is the result of particle settling and the larger particles with higher hindered settling velocity have settled. The extent of settling depends on settling time with increases with settling distance.

The middle of the pipe shows particle distribution which is relatively uniform and there are only a few clusters as shown in Figs. 4.6 and 4.7. The particle content is fairly uniform as shown in Fig. 4.10. The particle distribution during the flow of slurry at the velocities used for the present investigation could not suppress settling as it is evident from the study of particle distribution. But it may be possible to overcome settling by effectively filtering out the larger clusters or by use of a still larger flow velocity.

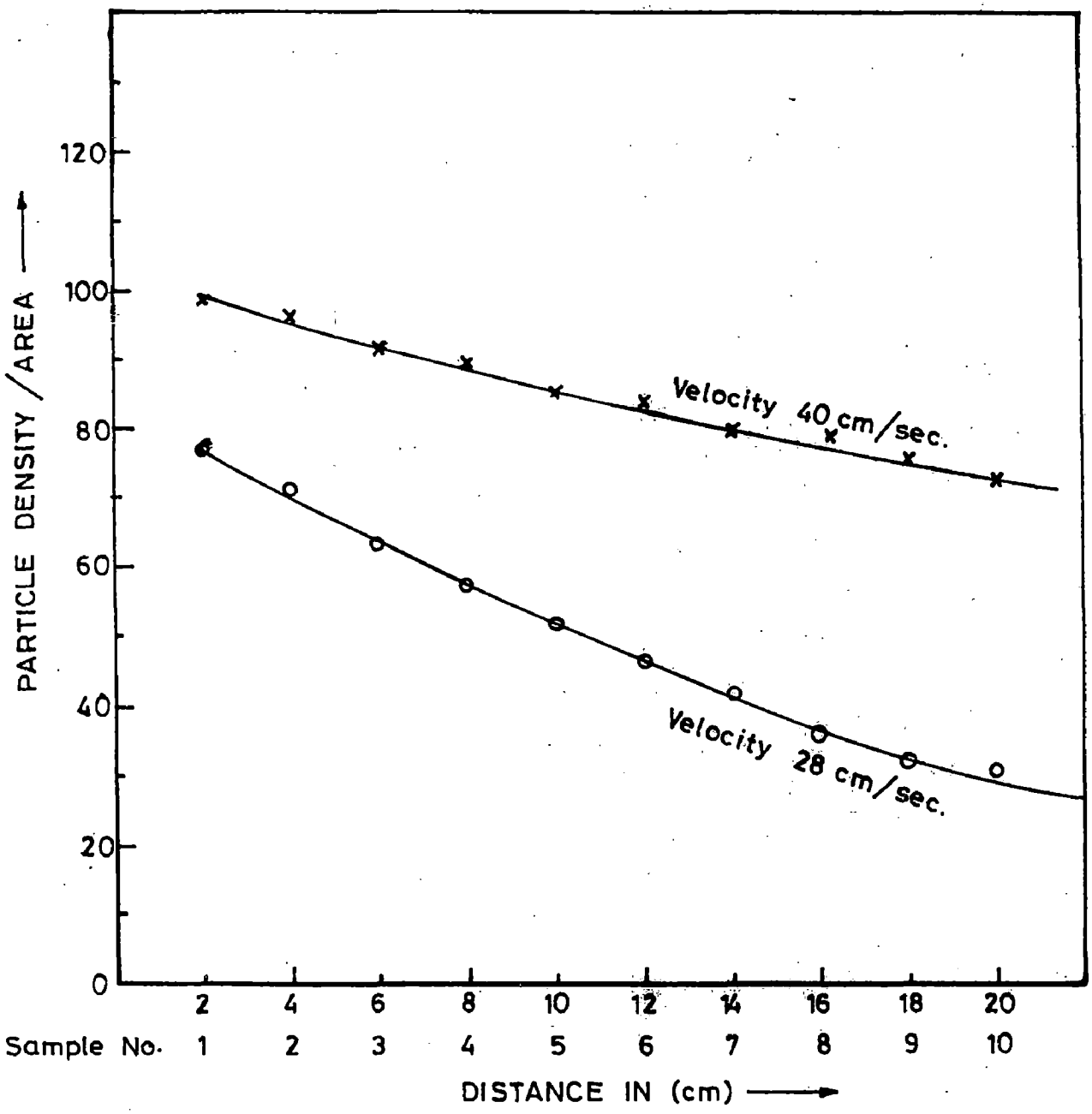
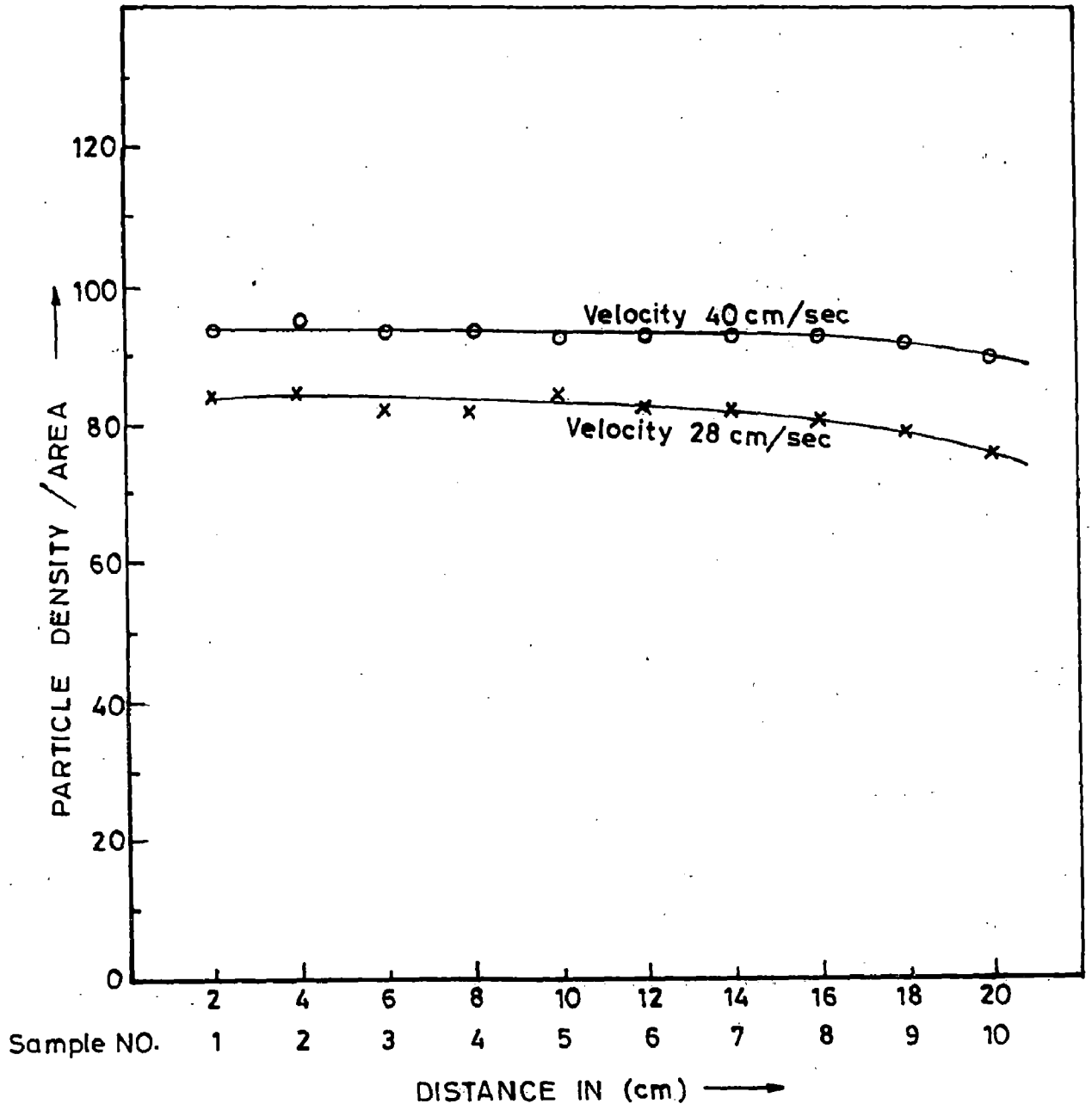

PARTICLE DENSITY /AREA
120
100
80
60
40
20
0
Velocity 40 cm/sec.
Velocity 28 cm/sec.
2 4 6 8 10 12 14 16 18 20
Sample No. 1 2 3 4 5 6 7 8 9 10
DISTANCE IN (cm)
TOP PORTION

Fig. 4.9



MID PORTION

Fig. 4.10

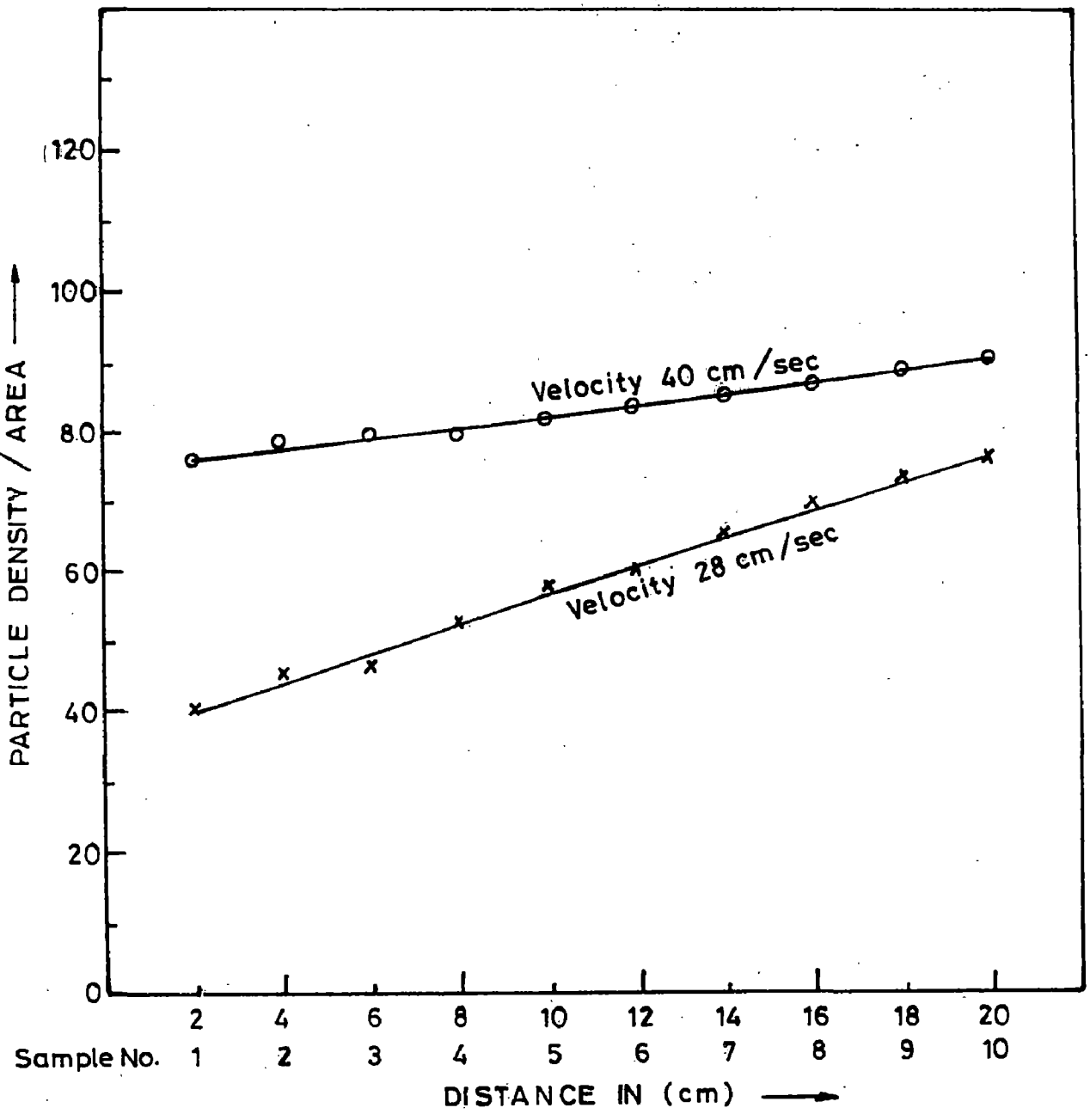

PARTICLE DENSITY / AREA
120
100
80
60
40
20
0
Velocity 40 cm/sec
Velocity 28 cm/sec
2 4 6 8 10 12 14 16 18 20
Sample No. 1 2 3 4 5 6 7 8 9 10
DISTANCE IN (cm)
BOTTOM PORTION

Fig. 4.8

CHAPTER - 5

CONCLUSION

The present study on the particle distribution during flow of a solidifying slurry in a pipe leads to the following conclusions.

1. A larger suction velocity results in suction of larger clusters of particles from the crucible into the pipe.
2. Larger clusters are able to settle even when a higher velocity of flow is present.
3. The extent of settling increases with a larger settling time as existing in larger distances of settling. Therefore, the particle content at the top reduces and that at the bottom increases with settling distance.
4. Particle content in the middle of the pipe shows a relatively uniform particle distribution along the pipe.
5. The flow velocities used in the present study could not carry the particle clusters so as to overcome settling.

CHAPTER - 6

SUGGESTIONS FOR FURTHER WORK

The present investigation is a pioneering effort to study particle distribution during flow of a melt - particle slurry in mould channels at different velocities. The experimental set-up has been fabricated and the preliminary study shows that significant results may be obtained. It is suggested that further investigation may be carried out at higher flow velocities using filters to eliminate large size clusters which settle at faster rate. The study may also be extended to other important composite systems like Al-SiC and Al-graphite systems.

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