MAGNETO-ABRASIVE MATERIALS AND METHODS FOR OBTAINING THEM

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Abstract: *Magnetic abrasive particles (MAPs) are crucial to ensure finishing quality and accuracy in magnetic abrasive finishing (MAF) processing. Conventional MAPs consist of ferrous particles and abrasive, such as Al_2O_3, SiC, ZrO_2, B_4C as well as diamond, cubic boron nitride, MgO, CeO_2 or fumed silica. The MAPs can be used as unbounded, loosely bounded or bounded. Here, ferrous particles, which are mostly conventional used magnetic particles in MAF process, provide force of grinding via magnetic field. But due to the corrosion and softness of ferrous materials, the post-cleaning of the surface finished by the MAPs containing ferrous particles becomes the most time-consuming and critical procedure in some ultraprecision MAF processing, other magnetic particles are urgent to need be developed to replace the conventional ferrous particles.*
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Keywords: *materials, finishing, abrasive, magnetic abrasive finishing.*

1. General concepts

Permanent improvement of technological processes of processing, aimed at improving quality, productivity, and economic efficiency is determined by increasing requirements imposed on the correct operation of machinery and equipment, as well as their increasing the degree of complexity.

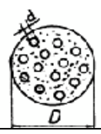
The erosion with fluids and suspensions abrasive is a part of the category processing procedures used, in general, to finish parts, aim being to ensure a high-precision dimensional, shape and position of the areas subject to agents of work. Important is also quality areas obtained, in the case of certain processes, roughness resulting being, sometimes, of the order of 10^{-10}.

The cutting by abrasion occurs when very small edges of some granules-free or bounded into a solid object or abrasive liquids and pastes, sometimes abrasive grains are to be placed in a magnetic field (magneto-abrasive finishing).

2. Magneto-abrasive materials

Development of technology for processing by abrasion has led to the development of new abrasive environments, a part of these being found in table 1.

Table 1: *Working media for MAF [1]*

Type	**Composition**
Ferromagnetic	Ferroboron, Ferrowolfram, Chilled iron, etc.
Ferromagnetic matrix + abrasives	Fe + TiC (15%), Fe + WC (20%), Fe + ZrC (10-20%), Fe + Al_2O_3 (10-20%), Fe + Cr_3C_2 (20-30%), Fe + W_2B_5 (10-30%)
Ferromagnetic matrix + diamond grains	 D=100÷250 μm d=5÷40 μm
Ferrofluids + abrasives	- *Ferrofluid*: dispersing medium; disperse phase; stabilizing agent. - *Abrasives:* Al_2O_3; TiC; Cr_3C_2.
Magneto-rheological fluid + abrasives	- suspensions of magnetizable particles(carbonyl iron particle - CIP) - non-magnetic base liquid (natural oil, mineral oil, water or glycol)

The methods for obtaining maximum performance of these working environments and improve the quality at the time of the processing areas with the help of it involves a research approach which requires an interdisciplinary research and collaboration between metallurgists (powder metallurgy) and technologists (machined specialists).

In case of magneto-abrasive finishing, the work environment consists of magneto-abrasive powders (ferri- or ferromagnetic particles such as ferrites or composite powders), or in suspension, i.e. ferrofluids or magneto-rheological fluids.

Magnetic fluids (ferrofluids) [2], [3], [4] are dispersions of sub-domains magnetic particles in a liquid base. Each colloidal particle in a magnetic fluid is a small permanent magnet which tends to align in the magnetic field direction. Assuming that the particles are small (~ 100Å), thermal agitation prevents their sedimentation. In addition, the particles are coated in order to prevent magnetic interaction. In this way results a complex mixture that acts as a homogeneous fluid even in the presence of a magnetic field applied from the outside.

The term of magneto-rheological liquid (MRL) relates to similar liquid as ferrofluids (FF), which solidify in the presence of a magnetic field. Magneto-rheological fluids have magnetic particles of micron scale, which means they are 1-3 orders of magnitude higher than those of ferrofluids. Magneto-rheological effect starts from the size of a particle greater than 10 nanometers. Magneto-rheological fluids (MRF) are composite or multiphase materials. They are usually made with some ferromagnetic phase dispersed in a non-volatile liquid, chemically inert. Typical materials include iron and mineral powders, silicone or synthetic oils. Magneto-rheological fluids have the ability to change their rheological properties.

3. Obtaining materials used as work environments in magneto-abrasive finishing

Because magneto-abrasive finishing uses magnetic particles and abrasives in magnetic field or being part of the magnetic fluid composition, some of the ways to obtain the magneto-abrasive powders and magnetic fluids will be presented.

Abrasive materials, especially the natural ones are obtained by crushing or grinding. In the case of synthetic abrasives, which are obtained by various methods of synthesis.

Among the most commonly used synthetic abrasives are silicon carbide, CSi, called carborundum, silicon nitride, Si_3N_4, boron carbide, B_4C called metalite, boron nitride, BN, also called white graphite and boron silicide, SiB_3 and SiB_6.

There are several recommended methods for obtaining materials used as work environments in magneto-abrasive finishing and some are listed below.

3.1 Obtaining powders through mechanical methods

The grinding process is the oldest method of obtaining ceramic, metallic and nonmetallic powders. The use of this method for disintegration of metallic materials is limited due to their plasticity, except for ferroalloys and intermetallic compounds which proved that the method is effective.

The general phenomena that occur in the disintegration of solid state materials are: the occurrence of core of generation of cracks, crack growth and rupture, after which new smaller particles are formed. A further reduction in particle size occurs only when the processes outlined above are taking place. The particle size of the powder depends on the material and operating parameters. The smaller the particles are, the more difficult are they to grind, because of their elastic and elastic-plastic response of the particles to external mechanical stress [5], [6], [7].

3.1.1 Ball mills grinding

Powder metallurgy uses conventional ball mills in grinding process for a relatively small number of powders, such as ferroalloys powders, hard metals powders, frail master alloys, and grinding fragile cathodes obtained by electrolysis, powders from iron cast and steel chips and so on.

The main disadvantage of the conventional grinding in ball mills is that the method can be generally applied only in the case of frail metals and alloys. Another disadvantage is that the powder is contaminated with material from the balls and the lining of the mill. Conventional ball mills are used successfully in grinding metal oxides required for manufacturing processes by reducing [7].

Figure 1 [7] presents a schematic of the operation of ball mills, a scheme which is available both for industrial and laboratory facilities.

The main element of the mill is the grinding drum. The diameter of the drum is between 200 and 1600 mm. It is equipped with a wear-resistant liner, madeof ceramic, manganese steel or sintered hard alloy. The balls are made of the same hard materials or harder. The degree of filling of the drum, including the grinding balls and the material to be ground is in the range of 40-60%. The speed of rotation is the main operational parameter of the process.

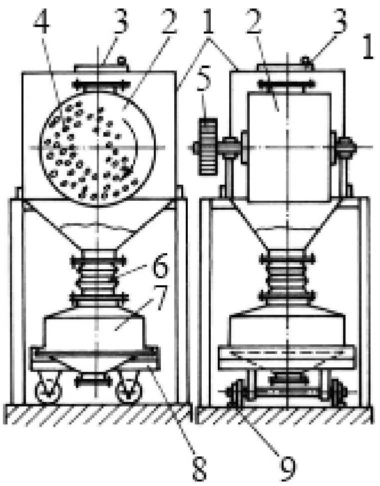


Figure 1: Components of a ball mill: 1.casing; 2.drum; 3. Hatch; 4. balls and material; 5. driving gear; 6. bellows; 7. shipping container; 8. cart; 9. rail.

At an optimal speed the balls are located at the top of the drum from which they fall onto the material. A low speed will keep the balls in the bottom of the drum, and thus there will be no collisions between them and the material. The faster the speed rate, the higher centrifugal forces will occur, so the particles will be prevented from taking contact with the material. In general the optimal grinding speed varies proportionally to the inverse square root of the diameter of the drum.

3.1.2 Spraying

Spraying is a mechanical method for obtaining the metal powder which consists in the disintegration of a liquid metal vane under the action of high energy sources. In general, the energy source can be produced by jets, steams or gases, by centrifugal, capillary or ultrasound force [8].

The spraying is carried out in two stages. In the first phase, the powder is obtained by melting, spraying and solidifying-cooling. In the second stage, the powder is dried (if possible), heat-treated, sifted and prepared to meet the requirements for sintered parts manufacturer.

The raw materials needed to produce powders through spraying are metallic or non-metallic waste.

A. Water spraying

Water spraying is currently the most important manufacturing method of metal powder, especially those based on iron.

The raw material is selected for melting. The melting can be accomplished in electric arc furnaces, by induction, plasma or laser. After elaboration, the furnace is tilted and the liquid material inside the funnel for molding is discharged and flows within the calibrated orifice of a ceramic nozzle into the spraying nozzle (Figure 2).

The atomizing nozzle has the role to taper water under pressure (up to 300 bar at the top of the cone), which at the impact the liquid metal produce its disintegration.

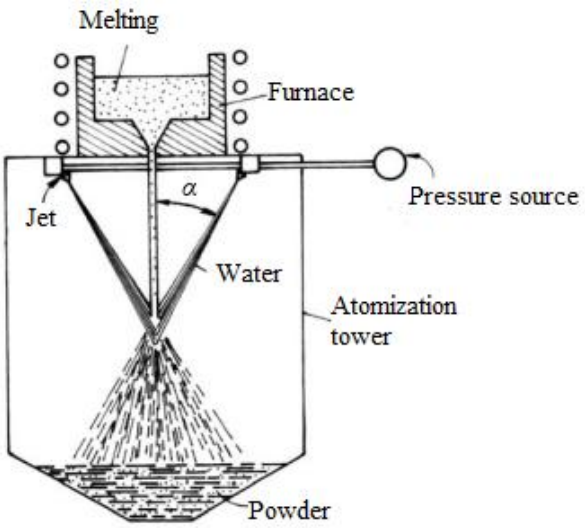


Figure 2: Water spraying process [8]

After spraying, the water is recycled and returned in the process. The powder is extracted with a pump from the atomisation tower after passing through a sift is sent to the drying installation.

B. Gas spraying

In the case of gas spraying, the liquid metal is disintegrated in the form of particles by a stream of gas which may be air, nitrogen, helium or argon. Depending on the melting temperature of the material, the process can be carried horizontally or vertically.

The gas spraying in a horizontal direction is suitable for materials with lower melting points.

The vertical spraying (Figure 3) is suitable for materials with high melting points.

The vertical stream of molten metal is converted to particles by a powerful stream of gas under a pressure equal to 12 MPa, and which speed reaches Mach 2 (720 m / s) in the spray nozzle. In most cases, the angle in which the gas makes contact with the metal is 40^0. The gas is removed from the spray chamber via a cyclone where the fine particles are deposited also. The gas is then recycled. Due to the relatively lower cooling speed of the particles atomization rooms have large dimensions, a complete installation for atomization could be up to 20 m.

The efficiency of the process is similar to water spraying. The particle size is between 20-300 μm. The obtained powder particles have a spherical shape, and frequently are gaps due to the gas produced in the process.

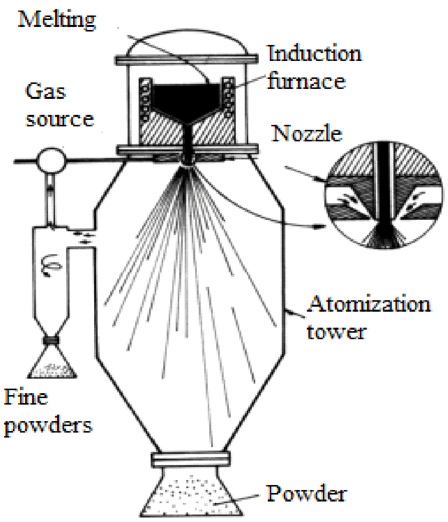


Figure 3: Vertical gas spraying process [8]

The air spraying was the first process of the atomization processes applied for iron powder. The molten metal used for spraying contains iron and 3.5% C. The molten metal is disintegrated by a series of side air jets. The fine particles fall into an enclosure containing the water and solidify. The particles have their surface oxidized and the powder contains up to 6% O_2. The powder is filtered and dried for further processing.

3.1.3 The Coldstream process

The Coldstream process implies cold impacting of the granules on a manganese steel wall and it is a highly productive process. Crushed larger sized granules are projected with an air jet having a pressure of 0.7 MPa at room temperature (Figure 4).

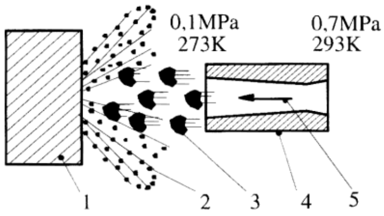


Figure 4: Obtaining metallic powders through Coldstream:
1 - steel wall; 2 - metal powder granules; 3 - large granules; 4 - nozzle; 5 - compressed air.

When the jet with the metal particles leave the nozzle, due to the sudden decrease in pressure for from 0.7 to 0.1 MPa, there is a sudden drop in temperature at about 20° C, which causes the material to become fragile and easily broken. By recirculating is reached the desired particle size.

3.2 Obtaining powders through physical-chemical methods

The main chemical manufacturing processes assume reduction of metal compounds such as oxides, carbonates, nitrates gas (usually hydrogen), or solid chemicals (carbon or reactive metals). In most cases, the metal compound to be reduced is in the solid state.

3.2.1. The Höganäs process

One of the most important methods for industrial-scale production of iron powder is direct reduction of magnetite (Fe_3O_4) with carbon. Magnetite ore is rich in iron and is found in sufficient quantities in the north of Sweden.

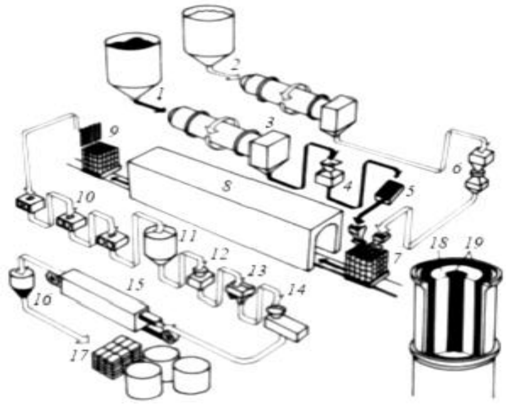


Figure 5: 1.iron ore; 2. reducing mixture of coke and calcium carbonate; 3. drying 4; shredding; 5. Sieving; 6. magnetic separator; 7. filling the ceramic tube; 8. reducing mixture at 1200°C in tunnel furnaces; 9. discharge; 10. primary shredding; 11. storage; 12. shredding; 13. magnetic separation; 14. grinding and sieving; 15. strip annealing furnace at 800-900 ° C; 16. equalizer; 17. packing; 18. iron ore; 19. reducing mixture.

The method of transformation of this ore in powder was developed in Sweden since 1910 by Höganäs company. The resulting sponge iron powder is one of the basic materials used in the preparation of sintered parts for machine manufacturing and more than half of the annual production of powder is obtained by this method, described in [7], [8], [9].

3.2.2. The carbonyl method

Obtaining the powder of Fe, Ni, Co, Cr, Mo, W, etc. through this method, is based on forming of carbonyl by the action of carbon monoxide on the metal, followed by decomposition of the CO in carbonyl and fine metal powder.

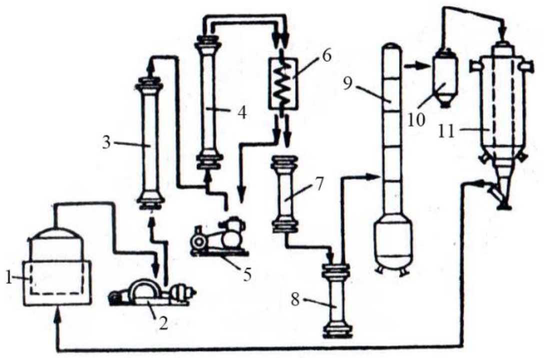


Figure 6: 1 - Gas meter(s) with CO; 2 - compressor; 3 - dryer; 4 - the synthesis column; 5 - circulation pump; 6 - cooler; 7 - high pressure tank; 8 - tank; 9 - rectifying column ; 10 - evaporator; 11 - reactor for obtaining of powder by carbonyl decomposition of nickel.

3.2.3. Obtaining metallic powders by electrolysis

Electrolysis allows to obtain metallic powders by a proper choice of electrolysis process parameter so that the metal should deposit on the cathode in the form of powder. Electrolysis can be done from water based solutions of the metal salts (copper, tin, iron, silver), or the melt of metal salt (tantalum, uranium, niobium, titanium, zirconium). The factors that are influencing the form under which the powder is deposited are electrolyte concentration, temperature, current density, electrolyte stirring, moving or vibrating electrode.

Several compositions for the deposition baths were researched. Electrolytes based on chlorides or sulfates are recommended, analogously to compact iron deposition alkaline electrolyte with suspensions of iron hydroxides in alkaline environments, with recommendations for submitting compact and fragile layers that can be further transformed into powder by grinding [9].

At low current densities, compact but fragile metal is lodged, and it can be easily crushed. At average current density, porous metal is lodged, and at high current densities, the powder.

Electrolytic deposition of metals in dispersed form is applicable to nearly all metals. Electrolysis allows also obtaining alloy powders such as Fe-Ni, Fe-Mo, Ni-Mo, Fe-Cr, Fe-Ni-Mo, etc.

The main advantage of this method is the possibility to manufacture high purity powders, even in the case of less pure raw materials; the particle size can be also varied to a degree up to a colloidal smoothness.

The main disadvantage of this method is the high price of the powder (3 ... 4 times more expensive than the powder obtained by spraying) so that they are only used in the manufacture of special products.

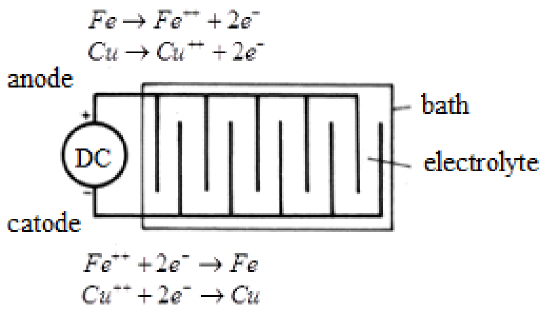


Figure 6: Electolysis scheme [8]

3.3 Obtaining magneto-abrasive powders

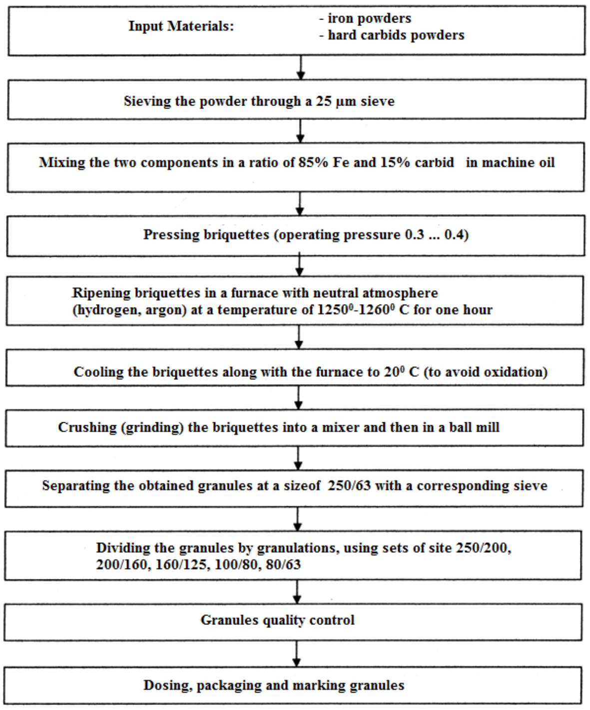
Magneto-abrasive powder matrix composed of ferromagnetic and abrasive use the two variants: one with free abrasive [10], and with bonded (incorporated) abrasives [11].

The most known methods of producing magneto-abrasive powders include sintering or melting (fusion) of mixtures of Fe and abrasive grains. These methods are quite complex and expensive, as it requires high temperatures, certain types of furnaces and presses. It was found that it is more advantageous for iron and abrasive particles to be linked with the help of adhesives [12], [13].

Percentage that are recommended to be used with this method is 60-90% magnetic component, the remaining 10-40% abrasive and adhesive [13].

Table 2 presents a method for obtaining magnetic-abrasive powder [1].

Table 2: Obtaining magnetic-abrasive powder [1]



3.3 Obtaining magnetic fluids

3.31. Preparation methods of magnetic liquids

The Preparation methods for magnetic liquids such as solutions of colloidal lyophilized particles ferry or ferromagnetic, which are stable to agglomeration and sedimentation, even under the action of external forces, need to meet the following essential requirements, [14], [15]:

• the solid magnetic material must be in a ultra-dispersed form such as nanoparticles ranging in size between 3 and 15 nm;

• the surface of the nanoparticles will be covered in a suitable mono- or bimolecular adsorbed layer, its nature and composition being determined by the physical and chemical properties of the nanoparticles and the basic fluid.

One of the first methods of obtaining magnetic nanoparticles was the mechanical method of dispersion (grinding colloidal). Papell [16], has used the method of grinding ferrofluids in ball mills (mechanical dispersion method) for the first time, which he used them as engine fuel for spaceships. In order to accomplish this, he used different Fe, Co, Ni magnetic powders and some ferromagnetic metal oxides. The best results were given by magnetite (Fe_3O_4).

The electrodepositing method is used to obtain magnetic liquid having mercury as a dispersion medium. In a glass bottle a mixture of iron sulphate, nickel sulphate and a certain quantity of water is inserted. Also, a certain quantity of mercury is introduced, mercury which plays the role of the negative electrode (cathode) during the dispersion. Another electrode, in the shape of a disc which is not in contact with the mercury, plays the role of the electrode (+) (anode).

The experience gained, particularly in the last decade highlighted clearly the special advantages of the process based on obtaining ferrimagnetic nanoparticles (Fe_3O_4, $CoFe_2$-O_4, α-Fe_2O_3 etc.) by chemical coprecipitation, applied today for the production of practically all fluids marketed by specialized companies.

The processes applied to obtaining non-polar magnetic liquids with the exception of water, are presented schematically in Figure 7, in which the main phases involving obtaining the different types of magnetic liquid are presented.

The main factors that influence the synthesizing of the nanoparticles and then of the magnetic fluid are: the concentration of the metal ions in the solution, the nature of the coprecipitation agent, the pH value of the reaction environment, the temperature at which the coprecipitation reaction happens, the speed used to add the coprecipitation agent and the intensity of the stirring/ultrasonic.

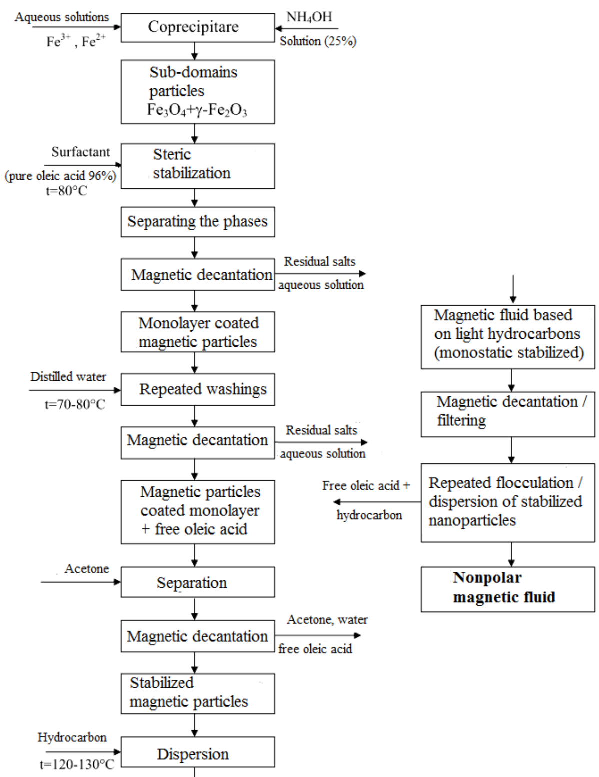


Figure 7: *Obtaining nonpolar magnetic liquid [2]*

In case of basic weak polar and polar liquids, for example diesters or alcohols, the appropriate choice of the second physically adsorbed stabilizer for the primary layer, is of a particular importance for obtaining magnetic concentrate polar liquids and at the same time very stable including for advanced dilutions. A special problem consists in determining the optimal ratio of the quantity of secondary stabilizer in relationship with the quantity of nanoparticles covered by the main stabilizer, which are to be dispersed in a certain basic polar liquid.

The magnetic polar liquid based on water involves special processes of obtaining. The preparation methods developed so far use either electrostatic stabilization [17] or double steric stabilization, used for the first time on this type of magnetic fluid in [18].

3.3.2 Methods of stabilization of magnetic liquids

There are three methods of stabilization to prevent contact between particles and to reduce interaction dipole-dipole: steric stabilization, electrostatic stabilization and mixed stabilization.

Steric stabilization (figure 8) involves the adsorption of long molecules at the surface of the particles. They present a polar end which is adsorbed and a chain which must be compatible with the basic liquid. The stabilization mechanism is called steric repulsion.

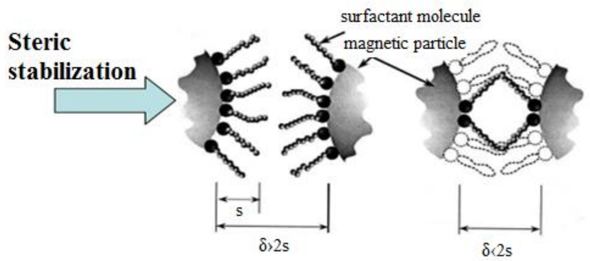


Figure 8: *Steric stabilization [20]*

The stabilizer compatibility (the surfactant) with the basic liquid is essential and the surfactant molecules must interact strongly with solvent molecules, stronger than between themselves. Otherwise the phenomenon of reversible flocculation may occur which leads to a decrease in the thickness of the surfactant as result of the interaction between chains or even as an attraction between strands of the neighboring particle, so the stability becomes precarious. The interaction between the chains is Van der Waals type.

Stability can be restored by replacing the basic liquid with a compatible one. There are incompatibility situations in which the surfactant desorbs, situations known under the name of irreversible flocculation.

The electrostatic stabilization has been applied for the first time by Massart [17], for the ionic magnetic fluids water-based. In this situation the steric stabilization is replaced by the electrostatic stabilization as result of the electrical charge of particles inside the solution, this way forming a double electrical layer.

Mixed stabilization is a combination of the two types of stabilization referred to above, in which the surfactant layer is electrically charged.

4. Conclusions

Increasing use of magneto-abrasive finishing technique in space, medicine, weapon industry, nuclear energy, electronics, geophysics etc. which requires a high precision, lead to further research onto the materials used in this process, in order to obtain new materials, more efficient and, as far as possible, with small costs of obtaining and operating as small.

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