Application and Performance Analysis of Intelligent Soft Materials in Oil and Gas Exploitation

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Abstract. In deep-sea oil and gas development, the problem faced by traditional materials is to consider the driving force of new material application. Soft matter science involves many fields such as mechanics, physics, biology, materials, chemistry and so on. It is regarded as a science in the 21st century and has received widespread attention in the world in recent years. The composition of soft matter is complex, and its motion does not depend on the atomic or molecular scale quantum mechanical action in the constituent units. During installation and service of deep water oil and gas transmission pipelines, the stress conditions are complicated, which not only meet the conditions of single load such as external hydrostatic pressure and bending moment, but also meet the conditions of combined action of external hydrostatic pressure and bending moment. The research and large-scale application of the physical mechanism of intelligent materials will lead to a major revolution in the development of material physics science. This paper analyzes the application and performance of intelligent soft materials in oil and gas exploitation.

1. Introduction

Intelligent soft materials are a large class of soft materials whose performance can be controlled during service. They have many potential applications in mechanical control, robots, artificial muscles, display and other fields, and have been widely studied at home and abroad. Intelligent materials should have sensing functions similar to those of human beings in general, that is to say, they should have corresponding sensing functions to the external environment, namely, signal sensing function (sensor function), self-judgment and self-conclusion function (information processing function) [1]. With the rapid development of economy, the living standard of human beings is continuously improving and the
consumption of energy is also increasing. Deep-sea oil and gas exploitation is the trend of the world's oil exploitation and has become a hot spot in the world's competition. Soft matter generally has its own structure and properties changed under the influence of external factors such as force, heat, electricity, light, magnetism and other physical and chemical effects [2]. However, the kinetic energy of the basic unit of a solid is much less than that of thermal motion. The composition of soft matter is complex, and its motion does not depend on the atomic or molecular scale quantum mechanical effects in the constituent units. The study of surface instability and morphology evolution of soft materials often requires the use of three-dimensional, large deformation and nonlinear theories of materials, and the morphology evolution after instability is extremely complex [3]. The research and large-scale application of the physical mechanism of intelligent materials will lead to a major revolution in the development of material physics science. This paper analyzes the application and performance of intelligent soft materials in oil and gas exploitation.

2. Intelligent Soft Material
Soft matter lies in the middle zone between the two extremes of fluid and ideal solid. Soft matter science involves many fields such as mechanics, physics, biology, materials, chemistry and so on. It is regarded as a science in the 21st century and has received widespread attention in the world in recent years. Piezoelectric ceramics are made by piezoelectric effect, which is the binding charge with opposite sign on the surface of both ends of the material due to the relative displacement of internal positive and negative charge centers and polarization caused by mechanical stress. Thermotropic liquid crystal is a liquid crystal state that varies with temperature, such as watches, liquid crystal televisions, computer liquid crystal displays, etc. Polymer functional membranes in functional membrane materials can be divided according to their different functions, which can be roughly divided into separation membranes, conversion membranes, etc. The most important functional membrane material is the separation membrane material. This kind of polymer gel can produce reversible and discontinuous volume changes due to different solvent types, salt concentration, pH value, temperature, electrical, magnetic stimulation and light radiation [4]. It has appropriate material storage shear modulus or Young's modulus; It is not easy to age and can match the working life of the vibrating member. The key to the design of intelligent water-based foam is foam stabilizer, which requires not only strong foaming and foam stability, but also reversible stimulation response at the gas/liquid interface or in the foam liquid channel. The rich physical connotation and extensive application background of soft matter have attracted more and more physicists’ interest. It is a challenging and urgent important research direction and has become an important frontier field in condensed matter physics research.

3. Application of Soft Matter

3.1. Liquid crystal and liquid crystal display
Liquid crystal is a common functional soft material, which is widely used in people's daily life. Micron-sized magnetic particles have high magnetic saturation because they are multi-domain magnetic particles. Once they are in an external magnetic field, they will have strong interaction and then have strong magnetorheological effect. Its characteristic is that the solid particles in the liquid can be polarized by an external electric field, and the polarized particles are arranged into a three-dimensional chain structure by mutual electrostatic action, thus increasing the apparent viscosity of the fluid. Lyotropic liquid crystal is a liquid crystal state formed when certain substances are dissolved in another substance. Even in the surface liquid layer of colloid, the attraction between adjacent molecules is greater than that between internal molecules, i.e. the colloid ball is subjected to surface tension. Fiber reinforced cement-based composites have excellent tensile and compressive properties, good crack resistance and durability, and are widely used in engineering fields. And the current intelligent materials are only widely used in known fields. It is rarely involved in unknown fields. Using the instability of liquid crystal flow under the action of electric field, scientists invented liquid crystal display technology. The liquid crystal material can coat a liquid crystal polymer solution in a capillary template, the solvent can
separate the capillary template after volatilization is completed, and the micro-tube actuator can be regulated and controlled by attenuating light irradiation. In addition, non-traditional spherical magnetic materials such as rods or wires are also considered as effective means to improve sedimentation and magnetorheological effect [5].

Magnetorheological fluid is an intelligent material with controllable magnetic field, which is usually composed of micron-sized magnetic particles, nonmagnetic carrier fluid and additives. Spherical colloidal particles at the gas-liquid interface form a two-dimensional ordered array, which can then be transferred to a solid substrate. In the process of using polymers, it is generally hoped that polymers can obtain very high apparent viscosity at very low concentration or reach the viscosity required by engineering. Some of them are similar to the "muscle memory" produced by people during exercise. When some corresponding signals are applied to the material, the material will immediately restore its original shape. The liquid crystal molecules are arranged in parallel, and the liquid crystal cell is transparent; When a few volts of low voltage is applied, the arrangement of liquid crystal molecules in the cell can be controlled and changed. It can play an active role in high-performance engineering materials, image display materials, temperature and chemical sensor core materials, nonlinear optical materials, piezoelectric materials and other aspects. When an external magnetic field is applied, tiny magnetic particles in ferrofluid can combine with non-magnetic particles to form gel-like network, thus enhancing magnetorheological effect. Therefore, electrorheological fluid damping members with specific structural forms for structural shock absorption and vibration suppression can be designed, which has become a hot topic in the field of vibration control engineering nowadays [6].

3.2. Intelligent material

During installation and service of deepwater oil and gas transmission pipelines, the stress conditions are complicated, which not only meet the conditions of single load such as external hydrostatic pressure and bending moment, but also meet the conditions of combined action of external hydrostatic pressure and bending moment. Because the cost of anticorrosion maintenance and component replacement for equipment in deep sea area is much higher than that in offshore area. Such as drill cuttings and weighting materials carried by drilling fluid, proppant in fracturing fluid, etc., and the construction technology requires these additional materials to be able to suspend in the solution, so the working fluid has certain suspension property, which is an essential requirement in some links of oil and gas exploitation operations. Under the action of the applied magnetic field, the nanoparticles will generate a strong magnetic dipole interaction force. This structure will greatly increase the viscosity of the fluid, which can be changed from liquid to "solid" [7]. Hydrogels are hydrophilic but insoluble polymers that can swell or shrink in response to changes in temperature, electric field or chemical substances, thus sensing changes in the surrounding environment. Then different substances have different permeability when passing through the membrane, so the substances in the mixture can be separated through the nature of the membrane. The method can enhance the magnetic saturation strength of the particles and further enhance the yield strength of the prepared magnetorheological fluid. The attenuation of energy can be controlled by controlling the viscosity of the electrorheological fluid by controlling the applied electric field.

In deep-sea oil and gas development, the problem faced by traditional materials is to consider the driving force of new material application. Generally speaking, polymer molecules will change in different degrees in acidic or alkaline media and under biological enzyme or light, high shear and other conditions. It will show a completely different state from its original shape and nature. And after the external magnetic field is removed, it can return to its original form. According to this, gel hands and other gel devices capable of grasping things are designed and manufactured. The soft substance characteristics of polymers can also be used in molecular devices, dimming materials, biomedicine, etc. In addition, there are high molecular material separation membranes made of polyolefins, polyamides and other materials. Polymer, hydrophilic silicone oligomer, organic metal silicon copolymer, superfine amorphous silica gel, organic clay and oligomer containing hydrogen bonds etc. are used to control the
structural vibration semi-actively or actively, and the applied electric field of the damper is controlled according to the corresponding control law to realize effective control of the structural vibration.

4. Application of Intelligent Soft Material and Soft Material in Oil and Gas Exploitation

Carbon fiber is a new material with excellent performance. Its biggest characteristic is light weight and high strength. Its density is less than 1/4 of that of steel, but its tensile strength is 7 ~ 9 times that of ordinary steel. According to the fiber reinforcement mechanism [8], the main factors affecting the fiber reinforcement effect are: fiber type, fiber length, fiber content, fiber orientation and surface condition, etc. When the dielectric constant of the particles differs greatly from that of the liquid, the particles are polarized in the electric field and arranged along the direction of the electric field, and the orientation of the particles can cause large changes in the transmission, absorption and reflection of light. There are more detailed, more specific and even completely different requirements for corresponding polymers in each link of oil and gas exploitation. Since energy conversion is involved in this process, more energy will be consumed, resulting in energy loss. The difference between it and ordinary functional materials is that it is responsive and closely related to intelligence information and bionics. Such as synthetic oil, mineral oil, water and other liquids can be used as carrier liquid [9], the basic requirements of which are non-flammable, good temperature stability and less pollution. The magnetic field strength can be adjusted by controlling the magnitude of electromagnetic coil current to change the viscosity of magnetorheological fluid, thus realizing the purpose of adjustable damping.

Carbon fiber has been widely used in aerospace, high-end engineering equipment, major infrastructure structural engineering, pressure vessels, sports and leisure products and other fields since its birth. Energy external dependence is related to national energy security. Excessive external dependence will not only cause a sharp increase in energy import costs, but also pose great risks in its transportation process. Failure to actively seek solutions will seriously threaten China's economic security. Table 1 shows typical carbon fiber series and their mechanical properties.

| Model | Tensile strength/MPa | Elastic modulus/GPa | Density/(g/cm³) | Specific strength/10⁷cm | Specific modulus/10⁹cm |
|-------|----------------------|---------------------|-----------------|------------------------|------------------------|
| T300  | 3560                 | 240                 | 1.66            | 2.04                   | 1.30                   |
| T700  | 4950                 | 260                 | 1.81            | 2.77                   | 1.26                   |
| T800  | 5520                 | 280                 | 1.83            | 3.05                   | 1.71                   |

The main purpose of mixing fibers such as cement matrix material is to overcome the brittleness defect of matrix material, enhance its toughness, and improve its microcrack propagation control ability and tensile strength. Carbon fiber has high tensile strength and high elastic modulus, coupled with low density, making its specific strength and specific modulus unique among many structural materials. However, after highly refining and abstracting, the above basic requirements for polymer solution are of great theoretical and practical significance for further study of polymer solution and control of its rheological properties. The molecules in an ideal solid move thermally near a fixed position and cannot change their sequence, so soft matter has both the thermal fluctuation behavior of liquid and the strong binding self-organization property of solid. In addition, it can also be made into magnetorheological elastic films that respond to low magnetic fields and applied to microfluidic mixers. Each nano-magnetic particle contains only a single magnetic domain and has extremely good stability due to Brownian motion. Therefore, deepening the basic research of temperature-resistant and salt-resistant polymers, improving the adaptability of polymer flooding to high temperature and high salt reservoirs, and expanding the application range of polymer flooding are the main tasks facing polymer flooding at present.

The stress curve of fiber-reinforced cement-based composites under axial pressure can be directly output by computer, and can also be converted from load, displacement and other data according to the
above formula. For each group of fiber-reinforced cement-based composites, the stress-strain curves of glass fiber, polypropylene fiber and polyvinyl alcohol fiber are drawn respectively, and the final stress curve is obtained through fitting (see fig. 1).

![Figure 1. Stress curves of three kinds of glass fiber reinforced cement matrix composites](image)

With the development strategy of oil and gas resources gradually moving from shallow water to deep water, even in ultra-deep waters with water depth exceeding 1500m, the development of deep water pipelines meeting the requirements of oil and gas transportation is an important foundation for the formation of deep water oil and gas resources exploitation strength. The fluctuation of sea waves makes the fatigue environment of the equipment very harsh, and the fatigue damage caused by sea waves is even greater than that caused by airplane flight. The molecular weight of the polymer is increased, so that the hydrodynamic volume of the polymer molecule is increased to obtain higher solution viscosity, and the temperature resistance and salt resistance of the polymer can be enhanced to a certain extent. Judging from the current development and application, intelligent materials have reached an indispensable position in some fields and will play an increasingly important role in the future. This feature, which can change according to the changes of external factors, can ensure that the intelligent membrane material has better application advantages in the field of microfluidic. This process is very rapid and usually takes place within a few milliseconds [10]. Moreover, this transition process is reversible. When the external pressure load borne by the pipeline exceeds the peak value indicated in the figure, the pressure load that the pipeline can bear will gradually decrease. For example, when the drilling depth is below 1500m, steel can be used; When the mining depth reaches 2,000 m, the huge tensile load caused by seawater will lead to the extension and deformation of steel. In the copolymer with low content of hydrophobic monomer, the reaction system can eventually become homogeneous. However, when the hydrophobic monomer content is high, the turbid solution is obtained. Even if the reaction time increases, the insoluble matter still does not disappear. Generally, it is difficult to dissolve high molecular weight polypropylene phthalamide. Fish-eye particles can still be seen in the solution after long-term dissolution. Taking the pipe cable out of the deep sea, maintaining it as required, and returning it to the original installation will not only consume the maintenance cost, but also lead to the shutdown of the project. Compared with when the interlayer is in non-bonded state and when the interlayer is in bonded state, the pressure borne by the pipeline increases faster, while the ellipticity changes less, and the corresponding ellipticity value when buckling occurs is also smaller. However, the organic-inorganic composite biomaterial combines the toughness of the organic component and the rigidity of the inorganic component, and can fully utilize the biological activity or reduction performance of the inorganic component or part of the organic component to form...
a hard tissue substitute composite material with comprehensive use performance. In the damper made of electrorheological fluid, when the applied vibration energy is transmitted through electrorheological fluid, it will be consumed due to overcoming the resistance caused by fluid viscosity. Under the action of electric field, dispersed phase particles are polarized to form dipole phenomenon. Particles with dipole moments are directionally arranged, and the particles form chains and bundles or form a certain structure from disorder to order, presenting electrorheological effect to the outside. When external magnetic field is added to its external environment, it can deform, and the degree of deformation will increase with the increase of magnetic field strength. The proportion of carbonyl iron powder in the material will lead to different magnetic field response strength.

5. Summary
At present, intelligent technology plays an increasingly important role in people's production and life. The application of functional soft materials can effectively respond to external stimuli. For example, the preparation of electrorheological fluid involves not only the selection of dispersoid, but also the selection of appropriate disperse phase and additives. The future research on soft material damping and damping materials will mainly focus on new materials and structures. At lower salinity, loose contact of polymer coils is sufficient to form a strong network structure in the solution. At present, intelligent materials are still in rapid development, and there are still many gaps to be solved. Intelligent materials can respond to some situations in a timely manner, which in turn reduces human labor and reduces the risk of accidents. As the research on soft matter has important scientific significance and application value for oil and gas exploitation, its future development trend cannot be underestimated.

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