Chapter

Research Progress of the Drill String Hardbanding Materials

Kai Zhang, Zhenquan Wang and Deguo Wang

Abstract

Among anti-wear technologies, hardbanding is the most effective measure to reduce the wear of drill pipe and casing. Many new hardbanding materials are introduced constantly, and the varieties of hardbandings are becoming more and more abundant. In this paper, the research history and status quo of the hardbanding materials in tool joint are reviewed. And the advantages and disadvantages of all kinds of wear-resisting materials are introduced. Finally, the development orientation in hardbanding materials in drill joint was pointed out.

Keywords: drill string, hardbanding, casing wear, anti-friction, anti-wear

1. Introduction

The drill pipe joint is an important part of drill pipe, which is used to connect the drill pipe to form a drilling string. It always adopts a larger wall thickness and larger outer diameter, which can increase the drill string strength and protect drill pipe. In the process of drilling, when the inclination of the well is larger or the drill string is subjected to larger lateral force, the drill pipe joint will contact with the borehole wall or the inner wall of the casing, which can cause both the serious drill string wear and the heavy casing wear.

At present, there are lots of anti-wear technologies of the drill pipe joint, such as drill string hardbanding, rubber drill pipe protector, casing pipe blast joint, etc. Among them, hardbanding is the process of bonding the hardbanding alloy with the parent steel of the drill pipe (**Figure 1**), which has the advantages of stable performance, simple operation, and easy maintenance [2]. At the moment, hardbanding is the most effective measure to reduce the wear of drill pipe and casing among these anti-wear technologies [3]. However, with the development of oil and gas exploration and drilling technology, complex well structures, such as deep well, extended reach well, horizontal well, and highly-deviated well, are being used more and more widely. In addition, the formation structures, such as strong abrasive formation, fractured formation, etc., are becoming more and more complex in the process of oil drilling. All of these put forward higher requirements for anti-wear and anti-friction characteristics of hardbandings, so the development of new hardbanding materials has already been the task of top priority [4–6].

With the gradual solution of the problems in the field application of hardbanding materials, many new hardbanding materials are introduced constantly, and the varieties of hardbandings are becoming more and more abundant. For this paper, the development and application of hardbanding materials for drill pipe joints were reviewed. Furthermore, the development of a new hardbanding material

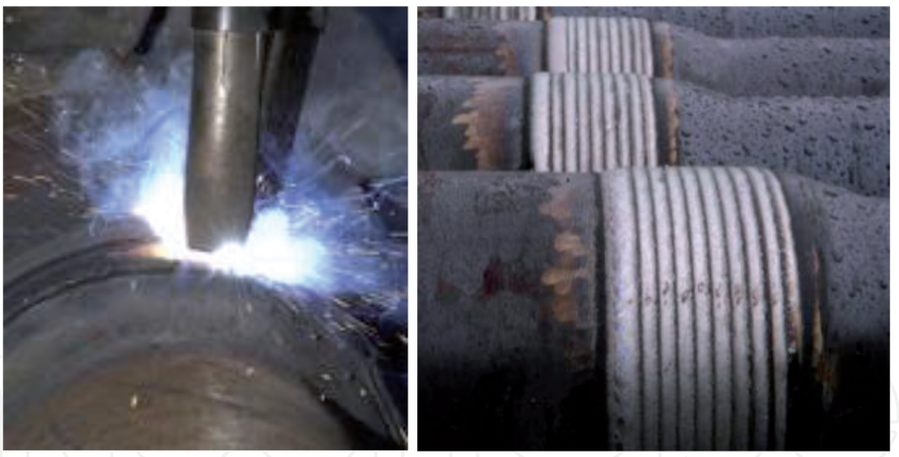

Figure 1.
Hardbanding welding process and morphology after welding [1].

independently developed by our team was reviewed. Finally, the weaknesses and development orientation of hardbanding materials were pointed out.

2. Development status of hardbanding materials

The development process of the hardbanding material is divided into two stages: the first stage is the cemented carbide material stage (from the 1930s to the early 1990s); the second stage is the "casing-friendly" material stage (from the 1990s to the present) [7].

2.1 Cemented carbide material stage

The cemented carbide hardbanding material was invented and marketed by Hughes Tool Company in the 1930s, which was designed to prevent the abrasive wear of drill pipe joints in the open hole section and improve the service life of drill pipe. This hardbanding material is composed of low carbon steel matrix and carbide particles, which is a very effective method of protecting drill pipe joints in shallow wells (<1500 m) and vertical wells (well deviation below 2°) [8, 9].

But as wells become more complex, the depth of the well is getting deeper, and the angle of the well is getting larger. The casing failures caused by the hardbanding of cemented carbide became more and more serious, which had aroused wide concern [10]. A lot of experimental studies have shown that during rotary drilling and tripping, the cemented carbide particles embedded in it will be soon exposed, because of the relatively soft base alloy of this wear-resistant belt. These exposed cemented carbide particles will cause serious abrasive wear on the casing wall and finally cause the casing failure.

In order to avoid the loss caused by casing failure, it was decided to stop using the cemented carbide hardbandings. Only the smooth drill pipes without hardbanding or other anti-wear technologies (such as rubber drill pipe protector, casing pipe blast joint, etc.) were allowed. Other anti-wear technologies could reduce casing wear to some extent but were generally faced with many problems, such as high cost, complex structure, difficult installation, low life, easy to cause downhole accidents, etc. [11].

Therefore, the major technical service companies began to develop new materials to replace the cemented carbide material. These materials are generally characterized by low friction, small wear to the casing, and high hardness, which can

protect the drill pipe joint to a certain extent. Since then, the development of drill pipe joint hardbanding material has entered the stage of "casing-friendly" material.

2.2 "Casing-friendly" material stage

"Casing-friendly" material has a low friction factor, resulting in lower casing wear. Small friction and friction heat can be produced when this hardbanding material is in contact with the inner wall of the casing. There are two main types of "casing-friendly" materials: one is the "amorphous" hardbanding material; the other one is the "crystalline" hardbanding material. The crystalline material refers to a material in which atoms follow a certain law in the arrangement. On the other hand, the material whose internal atoms are arranged in an irregular state is called the amorphous material [12, 13].

2.2.1 "Amorphous" material hardbandings

In 1990, Liquidmetal Technologies LTD developed a chromium alloy hardbanding material, named Armacor MTM. This material is an "amorphous" chromium alloy, the microstructure of which has no grain boundary and is distributed in a single atomic structure. The outstanding feature of this metal structure is that it has a very low friction factor. Therefore, the wear of the casing is very small, which can greatly reduce the wear of the casing. It is the first kind of "casing-friendly" hardbanding material, which represents a significant improvement in hardbanding technology. But because the "amorphous" hardbanding has only a very thin layer with poor abrasion performance under the high pressure, the main shortcoming of this hardbanding material is insufficient wear-resistant ability, which makes the drill pipe joint not well protected [14].

Subsequently, the Liquidmetal Technologies company has developed some new hardbanding materials, such as Armacor MStar and Armacor TMax. Till now, Armacor MStar material is their most casing-friendly material [15]. Armacor TMax material is their hardest, most wear-resistant material, which is ideal for open-hole drilling environments. In addition to this, as amorphous materials, these materials can lead to improved corrosion resistance and resistance to reactivity at elevated temperatures (oxidation, vulcanization), which are suitable for geothermal well drilling and deep well drilling.

2.2.2 "Crystalline" hardbanding materials

At the end of 1992, Arnco Technology Trust, Ltd., developed a new generation of chromium carbide hardbanding material—ARNCO 200XT™. The hardbanding can effectively reduce the wear of the casing and ensure the durability of the drill pipe joint in the open hole section, which can minimize the wear of the drill pipe joint. However, with ARNCO 200XT, it is easy to generate micro-cracks in the application and welding process. Although it has no influence in the use process, all the cracked parts should be removed during the reapplication and welding. Subsequently, the company has developed many hardbanding materials, such as ARNCO 100XT, ARNCO 300XT, ARNCO 150XT, and ARNCO 350XT, to overcome the problems existing in ARNCO 200XT [16]. The tool performances of these hardbanding materials are shown in **Figure 2**.

Arnco Technology has led the hardbanding industry since pioneering the use of casing-friendly hardbanding two decades ago. To better understand the development of "crystalline" hardbanding materials, a more detailed introduction can be found in the following:

1. ARNCO 100XT hardbanding alloy [17]. ARNCO 100XT is an iron-base alloy containing chromium, manganese, and molybdenum, which can be welded seamlessly. Because of the above 50 rockwell hardness, the drill pipe joint can be well protected. The inherent low coefficient of friction is the most significant characteristic of Arnco100 XT hardbanding alloy. In the series of products of ARNCO, its anti-friction performance is the best, which can effectively reduce the wear caused by the contact between drilling pipe string and casing to extend the service life.

1. ARNCO 300XT hardbanding alloy [18]. As the "third-generation" product of Arnco Technology, ARNCO 300XT is an iron-base alloy including nickel, boron, and niobium, which is a chrome-free metal material with little environmental pollution. ARNCO 300XT can be directly welded on the worn 100XT and 150XT hardbandings, which increases its applicability. Because of the above 60 rockwell hardness, its wear resistance is much stronger, which can be used in the open hole in extreme grinding geological structure. Besides, the wear on the casing can be reduced effectively, which can obtain the lowest radial wear on the inside-wall of the casing.

2. ARNCO 150XT hardbanding alloy [19]. As the "fourth-generation" product of Arnco Technology, ARNCO 150XT is a kind of advanced crack-free and casing-friendly hardbanding, which inherited the advantages of ARNCO 100XT and ARNCO 300XT. The wear-resistant capacity of ARNCO 150XT is between ARNCO 100XT and ARNCO 300XT, and the anti-friction capacity is higher than ARNCO 300XT and ARNCO 100XT. It's worth mentioning that repair welding can proceed under various external conditions without any crack, which can further enhance its applicability. Specifically, it can prevent the hydrogen sulfide corrosion and withstand high torque and high temperature in severe drilling conditions in extended reach wells, deep wells, and horizontal well, because of its maintaining of a certain toughness.

3. ARNCO 350XT hardbanding alloy [20]. As the "latest-generation" product of Arnco Technology, the wear resistance of ARNCO 350XT is further enhanced (compared with the ARNCO 300 XT), and the damage to the casing is further reduced, which is at present the strongest wear-resistant performance among Arnco Company's products. It can be easily welded to new drill pipe joints and can be directly welded to on the ARNCO 100XT, ARNCO 150XT, ARNCO 350XT, and most other crack-free hardbandings without removing the original hardbandings.

4. NonMagXT™ hardbanding [21]. The appearance of nonmagnetic drill pipes raises an even newer requirement for hardbandings. NonMagXT™ is a newly developed nonmagnetic hardbanding, which is a patent-pending iron-based alloy system. This hardbanding features clear advantages over nickel and other iron-based nonmagnetic hardband products, which can enable easy, crack-free application onto stainless steel. It can also deliver exceptional wear resistance, greater ductility, and resistance to damage while in service.

2.2.3 Other hardbanding materials

The development of new hardbanding materials with high performance has already attracted the attention of the industry. Many technical service companies have developed new materials. Major products can be found in the following:

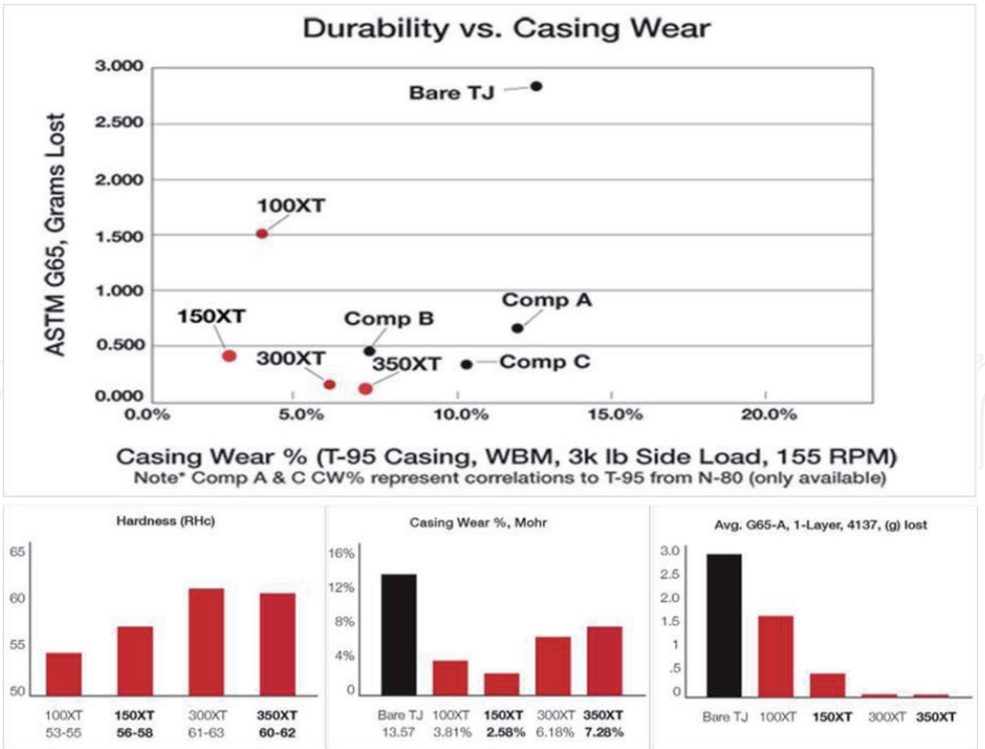

Figure 2.
Tool performances of ARNCO hardbanding materials [16].

2.2.3.1 Postle industries hardbanding

Postle Industries has developed some new hardbanding materials, such as Duraband® NC hardbanding and Tuffband® NC hardbanding:

Duraband® NC from Hardbanding Solutions is a 100% crack-free casing-friendly hardbanding, which can provide maximum protection of the tool joint and casing as well as workstring completion tubing [22]. Duraband® NC consists of a hard but tough tool steel matrix with a high volume of tightly packed micro-constituents, which ensures a non-cracking hard band with excellent wear resistance in open hole drilling as well as being casing friendly.

Tuffband® NC is a high hardness hardbanding which can meet different application requirements [23]. When used by itself, it is especially suitable for casing-friendly hardbanding applications. When casing protection is not a factor, it can be used as a weld matrix with tungsten carbide (WC). Tuffband® NC is applied crack free and prevents spalling even under the most extreme drilling conditions and is 100% rebuildable.

2.2.3.2 TE metal works hardbanding

TE Metal Works specialize in 100% nonmagnetic applications for all directional and vertical drilling. TE NM1X hardbanding developed by TE Metal Works is an alloy which is 100% nonmagnetic and 100% crack free [24]. This hardbanding will outlast 3 times the length of non-mag welding alloys.

2.2.3.3 HBK series hardbandings

HBK series hardbandings are developed by Kooben Technology [25]. Kooben is only one company in China with the ability to research, develop, and manufacture

hardbanding. Kooben's hardbanding product line now has three grades. They are HBK 100, HBK 150, and HBK 300, which are suitable for any application. The performances of their hardbandings are similar to those of Arnco hardbandings. They can offer at the industry's most competitive prices and are compatible with all Arnco hardbandings. Besides, the client testing phase of nonmagnetic hardbanding wire has begun. In addition, Kooben is also one of the few companies in the world that have nonmagnetic hardbanding wire products.

2.2.3.4 Some hardbandings made in China

In addition to Kooben products, some "casing-friendly" materials can be occasionally reported on the Internet, and most of them imitate the foreign products. For example, Nate707J hardbanding material developed by Xi'an Nate Petroleum Technology Co., Ltd., is an iron-based amorphous hardbanding alloy, whose wear resistance is basically equivalent to that of ARMACOR Mstar and 3.8–3.9 times of that of ARNCO 100XT [26]; BoTn3000 hardbanding material produced by Shanghai BoTeng Welding Consumables Co., Ltd., is a chrome-free hardbanding material with high hardness and good wear resistance, which has reached the advanced level of similar products abroad [27]. In addition, some China units, universities, research institutes, and other institutions are studying the production of new hardbanding materials. Although China's "casing-friendly" hardbanding materials have started, some hardbanding materials have made great progress. Some properties are even better than similar foreign hardbanding materials. However, most of them are still in the research and experimental stage and have not been mass-produced and put into application [28].

3. Development status of diamond composite hardbanding materials

At present, mechanical properties and wear resistance of hardbandings have been dramatically advanced. Although such improvements have been made, hardbandings and casings still suffer from friction and wear issues. The materials of existing hardbanding products are mostly iron-base alloy materials, so the problem of wear and tear is always unavoidable because of the pairwise similarity of elements. Therefore, if nonmetallic materials with high wear resistance are used to produce hardbandings, the wear problem will be greatly solved.

Polycrystalline diamond (PCD) is widely used in oil and mining explorations due to the advantages of homogeneous hardness, good toughness, and easy processing. And furthermore, PCD has a high wear resistance and low friction coefficient. Even in a high-temperature environment, it can also maintain its excellent performance. Thus PCD is obviously an ideal hardbanding material which could accomplish the optimum balance of drill string improvement and casing wear reduction [29].

Zhang et al., of the China University of Petroleum, Beijing, has developed a new hardbanding material (shown in **Figure 3**), called PCD reinforced WC matrix composite (PCD composite for short), which is a kind of homogeneous composite material of fine property [30]. This hardbanding material has a strong resistance to wear, which can be very good to prevent the drilling pipe joint wear in the strong abrasive formation. Because of the extremely weak wear of the iron foundation material, the casing can be well protected with small friction factor and friction resistance.

In order to understand the relationship between the raw material's properties and its tool performance, the material properties and drill pipe hardbanding performance of this PCD composite were investigated [29]. We find that the

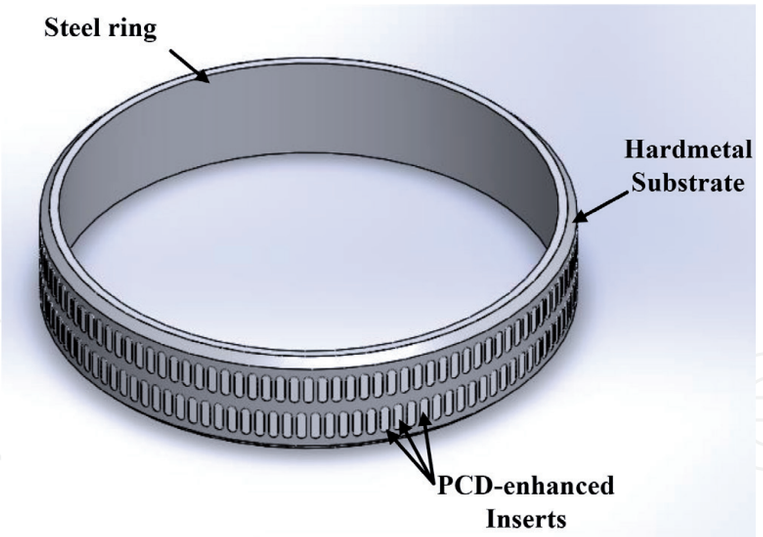

Figure 3.
Schematic description of PCD composite hardbanding.

excellent anti-friction property and reasonable hardness of this PCD composite hardbanding are the primary reasons for its enhanced tool performance. Besides, a height difference was found at the border between the PCD part and the WC matrix part, which is advantageous to form lubricant film to improve the lubricating performance. To better understand its performance, the friction and casing wear properties of PCD composite hardbanding were also investigated. The results indicate that as the applied load and sliding speed steadily increase, the friction coefficients of PCD composites decrease. In addition, the casing wear rates increase with increasing load but decline with sliding velocity. The dominant wear mechanism of the PCD composite is the micro-cutting wear, accompanied by adhesive wear [31].

Due to the poor thermal stability of PDC, the performance will be affected in high-temperature geothermal wells and deep wells [32]. In many polycrystalline diamond composites, the thermally stable polycrystalline (TSP) diamond can exhibit excellent anti-friction and good anti-abrasion, which also can be achieved in an environment of high temperature and super high pressure and thermally stable up to 1200°C. Thus, in order to improve the thermal stability, the TSP was used to replace the PCD to produce this hardbanding. By proving experimentation, TSP composites could satisfy the requirements of protecting the casing and the drill pipe at the same time when drilling deep holes. This perfect performance is dependent on the adsorbed lubricating liquid on the rubbing surface and the formation of height difference between the TSP part and the WC matrix part [33].

The overall results demonstrate that the PCD composite series hardbandings are extremely promising for drill pipe hardbanding applications.

4. Conclusions

1. At present, the research on hardbanding materials is still in the stage of "casing-friendly" materials. The hardbanding material is mainly developed to the directions of high wear resistance, high casing friendliness, and high rewelding.

2. Although more and more hardbanding products appear, ARNCO series hardbandings developed by Arnco Technology companies are still the best hard-

banding materials. The latest products ARNCO 350XT and 150XT are the best products with wear-resisting performance, which can guarantee 100% no crack.

3. In China, some "casing-friendly" hardbanding materials can be occasionally reported on the Internet, and most of them imitate the foreign products. The material performance has still a certain gap compared with mature products. Chinese research institutions should pay attention to the development of new wear-resistant belt materials to accelerate the development of a reasonable price. If the excellent performance of new wear-resistant belt material can be obtained, then China's capacity for independent research and technology level will be enhanced.

4. PCD composite series hardbandings, which are extremely promising for drill pipe hardbanding applications. This hardbanding material has a strong resistance to wear, a good casing protected with small friction factor, and friction resistance.

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Author details

Kai Zhang[1,2*], Zhenquan Wang[3] and Deguo Wang[4]

1 School of Engineering and Technology, China University of Geosciences, Beijing, China

2 Key Laboratory on Deep Geo-Drilling Technology of the Ministry of Land and Resources, China University of Geosciences, Beijing, China

3 College of Petroleum Engineering, China University of Petroleum, Beijing, China

4 College of Mechanical and Transportation Engineering, China University of Petroleum, Beijing, China

*Address all correspondence to: zhangkai66@cugb.edu.cn

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