A New Type Alloy-coated Anti-Skid Steel Rail

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ABSTRACT
This article is intended to introduce a new type of alloy coated anti-skid steel rail, which is using alloy coating on the rail head to protect the vehicle wheel from sliding on the coated rail. Vehicle wheel can slide on the normal steel rail and the adhesive factor will be weakened down significantly if the steel rail gets wet due to rainy weather or gets contaminated by oil or leaf. The root cause for the adhesive factor weakening is that there is a water or oil film formed between the wheel tread and rail head, keeping the friction force down and the wheel blank run on the rail ①. Alloy coating on the rail head can damage the water or oil film to maintain the adhesive level, as well as to increase the friction force on the rail to protect the wheel tread from sliding.

**Key Word:** Anti-skid alloy coated steel rail, increase the friction to improve the train wheel slide, alloy coating layer on the rail head to improve adhesive factor, wheel slide protection on wet rail though alloy coating on the rail, rail adhesion improvement through alloy coating

With the fast development of railway industry in China, more and more technical issues are coming up and vehicle wheel slide on the rail was one the major issue that has been found in high speed railway, metro railway, freight railway etc., particularly when the railway is paved with a gradient in an open environment that the steel rail can get wet when it rains. Wheel slide is a serious issue that would cause wheel tread worn out, WSP module in the braking system works continuously in an abnormal way. In some extreme cases, wheel slide

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would cause the propulsion system down and safety issues \( \Box \). Some of the rail in the Shanghai Hu-Ming overhead Line were paved with a grade of more than 15\% and many cases of wheel slide on the rail were found during rainy or snowing weather. Same issue was found in Wuhan Yang Luo Line & Guangzhou metro lines with similar railway ramp up where the railway comes out from underground tunnel to the ground depot.

1. CONDITIONS OF TRAIN WHEEL SLIDE

Train wheel can be sliding in many conditions particularly when the rail is paved with certain grade on the ground, in such case the propulsion force is bigger than the friction force that the rail could provide to the wheel. The rail grade should be carefully calculated with the train conditions (weight & speed & temperature, etc.) and propulsion forces, while the adhesive factor design (the friction pair) is fixed.

When water or oil or leaf drops on the rail head and the wheel runs over the rail, a very thin film could be formed between the rail head & wheel tread that normally leads the adhesive factor down significantly.

Rail grade cannot be avoided when pave the railway due to the vary landform but normally it should not be more than 30\% on the service railway and less than 40\% on the way in/out from tunnel to depot.

On the dry condition (means the rail head is dry and without any water or oil film), the max friction force should be carefully calculated in accordance with the adhesive factor & propulsion force. The balance point should be the max friction force equal to the propulsion force. When the adhesive factor weakens, the balance breaks down so wheel slide happens.

1.1 Wet condition may lead to the weakening of adhesive and wheel slide

When the rail is polluted by water oil or leaf and a train wheel rides over the rail, there will be most likely a film to be formed between the rail head and wheel tread. This layer of film is just like a lubricant film that causes the adhesive or friction factor down significantly. Normally the friction factor between the friction pair is 0.05~0.3, after pollution by water oil or leaf, the friction factor could be weakened by around 50\% \( \Box \) in this situation, the propulsion force could not apply 100\% on the rail to drive the train running and wheel would have blank run on the
rail. To prevent such blank run, the solution would be (A) to clean the pollution water oil or leaf from the rail to maintain the dry condition, or (B) to maintain the friction level by adding some material such as sand, etc. between the friction pair. Adding sand on rail to maintain the friction level is the general method in the industry because when the wheel over ride on the rail, the sand would help to break the film from forming and partially recover the friction force and wheel adhesion ④.

Adding sand to maintain the friction level may resolve the problem partially but not completely and create some other side problems. Firstly, the sand would also pollute the railway and create dust on the railway, secondly, adding sand in the rainy time would disturb the normal operations plan, thirdly, the sand between the rail and wheel may create problem for the electric conductivity because the rail is part of the power circuit loop, this is very critical to safety operation ⑤.

1.2 When the train runs or stops on the ramp up way of the railway, the train wheel may run blank or slide.

When train stops on the ramp up way, the train weight can be discomposed by 2 forces and one of the force F along the rail down direction will be major one that the propulsion force needs to overcome to drive the train ahead. If the friction force is not bigger enough, the propulsion force will not be able to apply on the rail, the wheel should run blank. See FIG. 1 below:

![Figure 1](image)

Figure 1. The solution should be to increase the friction force F1, which is to increase the friction factor or the wheel adhesion on the rail.

Adding an Alloy layer on the rail head can be a new method to increase the friction level and wheel adhesion on the rail. In principle, adding alloy layer is similar with adding sand to improve the friction and adhesion but much better than adding sand.

Adding an alloy layer between the wheel and rail is the straightest way to improve the adhesion and friction pair. But which of the pair we should add, on the rail head or the wheel tread? Obviously, the wheel tread is not suitable because we have to machine the wheel tread in timely basis to keep the wheel tread profile
as this is the most economical way for operations. So the best choice is to add an alloy layer on the rail. Adding an alloy layer by supersonic spraying the alloy power on the rail head, the alloy power will be melting onto the surface layer of the rail head as a whole, to form a firm alloy layer. The alloy layer will increase the roughness of the rail head surface while the normal rail will have a smooth surface after long time operation, see FIG 2 normal smooth rail with comparison to FIG 3 rough rail. It is obvious that when the wheel tread runs on the rougher rail, the tread is riding on the rougher alloy layer not the normal smooth rail head. The alloy layer is harder than rail and its sharp peak will pierce into the tread to increase the friction, this is why the alloy layer could improve the adhesion and friction.

![Figure 2.](image1)

![Figure 3.](image2)

The rail head surface can be rubdown smooth after heavy train running on it for long time, it is very hard to maintain a rough surface on the rail head for long time. The author spent long time to get a new process that can maintain a rougher surface of the rail head by wedding alloy powder on it. The hardness of the alloy layer allows the heavy train running on it for longer time than 2 years, after 2 years, we can reproduce the roughness on the rail to keep the friction and adhesion level to protect wheel slide.

In brief, the process to get a rough surface on the rail is below:

Normal steel rail $\rightarrow$ knurl # on the head $\rightarrow$ spray sand on the knurl # $\rightarrow$ supersonic spray wedding of alloy powder on the rail head.

2. **THE ALLOY LAYER WILL HAVE BELOW ADVANTAGES AND CHARACTERISTICS:**

The roughness can be controlled in a certain range (>Ra100) according to the real needs during the supersonic spray process. Roughness selection will have to be balanced with the life cycle of the wheel tread and friction force and other factors. The more friction force you can get from the rougher surface; the shorter
life cycle of the wheel you may have because the tougher friction will speed up the worn out of the wheel tread. Normally we can produce the roughness to be Ra100~120, as long as the sharp peak would be able to pierce into the wheel tread to damage the lubricant film.

The rough alloy layer will help to prevent the water oil or leaf from forming a lubricant layer between the rail and wheel tread because, if we observe the friction pair under the microscopic state, we should be able to find out that the hard sharp tungsten carbide or WC-Co or WC-Co-Ni-Cr powder will be able to pierce into the tread and damage the water oil film. The hardness of the tungsten carbide can be >HV800, which is 2 times of hardness than HB400⑥ while the hardness of the wheel tread is normally HB295~310⑦, this allows the hard and sharp tungsten carbide powder to pierce into the wheel tread to increase friction and adhesion.

The alloy layer allows the heavy train to override on its surface and maintain a higher level of wear resistance.

2.1 High impact resistance performance

The alloy layer is very well melted onto the rail surface so stripping resistance performance is good.

Alloy layer has very good electric conductivity. See FIGS 4 & 5.

![Figure 4.](image)

![Figure 5.](image)

No impact for ultrasonic flaw detection.
Great performance of antirust and corrosion.
Similar hot-shrinkage rate between the alloy layer and the normal rail body.
2.2 Anti-skid and wheel slide protection principle

Contact analysis between the wheel & rail under microscopic state to benchmark the normal rail and new rail with alloy coating explains the principles of anti-skid characteristics of the alloy coating layer. When the rail is polluted by water oil or leaf, there will be a film to be formed between the rail and wheel and this layer of film is just like a lubricant layer that leads to significant fading of the adhesion and friction. See FIG 6.

![Normal Rail Micro Structural Sketch](image)

Figure 6.

When add an alloy coating layer by supersonic praying alloy powder on the rail, the rail head surface will be formed with a rough peak and valley. When the rail is polluted with water oil or leaf, the water or oil will stay in the valley, and the alloy powder peak will break up the film and pierce onto the tread to build up a firm and reliable adhesion between the rail and wheel. See FIG 7 and partial enlarged FIG 8.

![Coated Rail Micro Structural Sketch](image)

Figure 7.
The sharp peak of the alloy powder/layer can be harder than the wheel tread. The alloy layer is melted onto the surface as a whole with the rail body. When the wheel runs over the rail, it will be difficult to wear the alloy layer out, which means, the life cycle for the alloy layer would be long. But for how long will it be? This needs to be verified in various real cases and theoretically, the life cycle of the layer will be related to a lot of factors such as duty time, train weight, thickness of the layer and composition formula of the alloy etc.

2.3 Production process of anti-skid steel rail and usage of the alloy coated rail

In brief, the production process for anti-skid steel rail will be to add knurl, sanding on the knurling area and supersonic plasma spray of alloy powder processes into the normal rail production process. The new process to produce anti-skid steel rail will keep the same rail profile without change but add an alloy coating layer of 0.3~0.5mm that is firmly melted with the rail body. The layer as said will increase the friction force and adhesion while maintain the rail physical mechanical characteristics without any change.

3. KNURLING

During the normal steel rail production process, the temperature of forming the rail profile will be very high, this allows knurling certain patent on the rail in process. When the rail cools down, it will be difficult to knurl on the rail head due to its hard surface. This is why that the knurling process needs to be added in normal rail production process. See FIG 9.
Knurling on the rail head will create lot of valleys and peaks, allow the alloy powder to be melted with the rail body in different dimensions and more areas to reinforce the binding performances with the rail body. The alloy powder “buried” in the valleys and combined with the valley walls from multiple dimensions will not be easily stripped off when heavy train over rides on the rail.

![Knurling on the head to create valleys and peaks](image)

Figure 9.

3.1 Spray sand to get rid of the stress after knurling

During the knurling process on the rail head, internal stress will be created and we need to add a sand spray process to get rid of the stress, as well as to remove the burrs on the peak & to round the valley.

3.2 Supersonic plasma spray of alloy powder on the knurled area

Supersonic plasma spray technology for alloy powder coating is recently populated in civil industry while previously this technology is developed for military use only. The spray gun and plasma generator can be available in the market.

Supersonic plasma spray process is to use plasma spray machine to spray the alloy powder onto the rail head surface, to melt the alloy powder onto the rail head as a whole. This technology is mature in welding alloy powder onto metal surface to increase the hardness, wearing performance, as well as for the purpose of rust & corrosion proof.

What is important to mention here will be the alloy formula. The formula should be developed after experiment and validation but normally tungsten carbide or WC-Co or WC-Co-Ni-Cr are the major materials composed.

FIGS 10 & 11 are the sketches after coating.
3.3 Type testing & validation program

Type testing & validation process should include but not limited to below items:

- Coating layer performance for wearing: one million runs of real train wheel wearing at AW3 or so.
- Coating adhesion testing: to test the adhesion force of the coating layer to the rail body
- Coating layer impact testing: use heavy objective to drop onto the coated rail to test the coating layer
- Rust proof & anti-corrosion test
- Ultrasonic flaw detection of the coated rail
- Field simulation and anti-skid validation on the railway line by spraying water, oil or putting leafs on the rail head.
Since the anti-skid steel rail is a new process product and there is no national standard for the product and its validation process. We would recommend some relative standards or process from military ship industry where some similar coating processes are applied on the deck to prevent slide of air plane wheels.

3.4 Usage of alloy coated rail

It may require removal of the coating at the very end of a rail before wedding 2 pieces of rails together in the field but this needs to be verified and validated. Theoretically, alloy coating layer should not impact the wedding process and wedding quality, the ~0.5mm layer coating at the rail end should not affect the wedding quality but anyway, validation will be still needed.

4. RAIL TREATMENT IN THE FIELD

For the existing rail that has wheel slide or blank run problem, to add an alloy-coating layer on the rail head would also work to increase the friction and adhesion to proof the wheel blank run on the rail. The process could be to use mobile sanding machine to get rough surface on the rail head and then to use mobile plasma ultrasonic spray machine to coat an alloy layer. We called this as “blank” layer because the layer is added on the “blank” rail head with no knurling. While the layer is coated on knurling rail head, we called this layer as knurling layer.

Since the blank layer is done on the blank rail head, the adhesion of the alloy layer to the rail head would not be as good as the knurling layer, the life cycle of the blank layer might be shorter than the knurling layer, but as a solution, this treatment will work immediately to resolve the wheel slide problem during raining or snowing season.

The lead time of the treatment process to add an alloy coating on the rail in the field could be quite short, with a speed of 5 m² or 10 meters long rail per day, it would be less than half month to add a layer in the field for a 200 meters long railway during the daily time slot, no impact to the daily operations.

The field coating layer can be in working condition right after the layer is done on the rail head. No drying time is needed.
5. COMPLIMENTARY CLOSE

Train wheel slide is a big topic for researches & discussions and involves wide & deep engineering technologies. Since the wheel slide result is so serious and it deserves more researches from wider aspects, this article is aiming to the rail head treatment to increase the adhesive factor of the rail, to help to open a new discussion and research for wheel slide protection.

In comparison with sanding on the rail methodology, rail cleaning and railway sheltering etc. to improve the adhesive & friction level & manage the rail condition, using alloy coated rail to increase the friction and adhesion should be the most effective and economic way.

REFERENCES

2. 《牵引力对机车轮轮轮轨黏着性能的影响分析》中图分类号：U260.115 文献标志码：A 文章编号:1001-8360(2014)02-0018-07
4. 《HXN5 型内燃机车撒砂系统优化研究》中图分类号 U262 文献标识码 A 文章编号 1674-6708（2013）90-0027-02
5. 《北美机车在撒砂和不撒砂情况下的轮轨磨损与粘着》，国内内燃机车，1987 年 10 期
7. 李家驹, 杨开庭, 应惠敏, 董泽发.《车轮和钢轨硬度匹配的研究》中国铁道科学 China Railway Science，1984 年 01 期，ISSN：1001-4632
8. 《激光熔覆 AlCrCoMnNiFe 合金涂层及性能研究》热加工工艺，2017 年 08 期