DEVELOPMENT OF A NEW GENERATION OF ADDITIVES FOR ALUMINIUM ROLLING LUBRICATION①

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ABSTRACT The characteristics of aluminium rolling lubrication and the functions of additives were analyzed; the compound mechanisms of the additives were studied. Based on these, a new generation of additives with good performance was developed, which can successfully resolve the contradictions between the lubricity and the annealing surface quality.

Key words aluminium rolling lubricity additives compound mechanisms

1 INTRODUCTION

The development of the additives for aluminium rolling lubrication in China may date back to 1980. From then on, some progress has been made in this field, but the home products are still much inferior in quality to those advanced additives in the world, thus having not been accepted by the domestic aluminium processing trades. From 1985 to 1995, based on the anlyses of the advanced foreign dispensation formulas, Central South University of Technology successfully developed the CSA series of additives for aluminium rolling lubrication which approach the world advanced level. In the recent years, on the basis of analyzing the compound mechanisms of additives, the authors successfully developed a new generation of additives with good performance for aluminium rolling lubrication.

2 DEVELOPMENT PROCEDURE AND DISCUSSION

2.1 *Characteristics of* Al *Rolling and Functions of Additives*

In the process of aluminium rolling, the lubricant film in the deformed zone is much thin, therefore, the rolled aluminium is at a state of boundary lubrication or mixed lubrication. The rollers exert pressure on the piece through this thin film and make it plastically deformed. In this case, the surface adsorbed film plays a key role in lubricating.

The lubricant for rolling is composed of base oil and additives, of which the base oil acting as carrier is non-polar hydrocarbons whose molecules are in disordered state. When it contacts with metals, it can also form weak physical adsorption due to the action of the surface potential layer of the metals. However, the adsorption strength of this physical adsorbed film is small, and it will rupture under very low normal pressure, thus leading to the direct contact of the friction pair. Therefore, pure base oil has low bearing capacity and high frictional coefficient. After a little amount of additives is added into the base oil, the strength of the lubricant film will increase significantly and the frictional coefficient will reduce noticeably, therefore, the surface adsorbed film formed by the polar molecules

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of the additives plays important roles in avoiding scuffing of the metal surface, reducing abrasion and frictional coefficients.

2. 2 *Constituents of Additives for* Al *Rolling*

The additives for aluminium rolling are generally composed of fatty acids, fatty alcohols, fatty acid esters and a little amount of germicides and anti-oxidants and so on. Some additives, especially some polar additives, should not be added, because the strong polar radicals in the polar additives will not only corrode the metallic surface, but also produce residues on the product surface after annealing treatment.

The modern aluminium rolling moves toward high speed and large reduction. The bad lubricity of the lubricants for rolling will often lead to the damage of the lubricant films, leave compressed scars on the piece surface, thus affecting the rolling quality of the aluminium materials. Therefore, in order to meet the needs of the world for high quality aluminium materials, alcohol series additives for strip rolling lubrication and ester series additives for foil rolling lubrication have been developed. Meanwhile, the compound mechanisms of the additives are being studied actively around the world.

2. 3 *Compound Mechanisms of Additives*

There are a lot of reports on the lubricating mechanisms of single component additives under the condition of boundary lubrication or mixed lubrication, but very few reports on the compound effects of multi-component compound additives. When a multi-component additive is dissolved in the base oil, there will be complicated interactions among the components and the base oil, which can be classified as three categories as follows.

(1) Synergistic effect. Due to the interactions among the components, the effect of the compound additive is better than the simple addition of those of all components.

(2) Addition effect. Due to no mutual disturbance among the components, the effect of the compound additive is basically equal to the simple addition of those of all components.

(3) Mutual constraint. Due to the mutual disturbance among the components, the effect of the compound additive is smaller than the simple addition of those of all components.

Therefore, the study of the mechanisms of the interactions among the components and the base oil and the functioning effects will greatly promote the development of a new generation of additives with good performance.

Table 1 gives the film strength and frictional coefficients of the lubricant for foil rolling lubrication containing 5% different single component additives. It is clear that the film strength increases and frictional coefficient reduces with increasing chain length for the same kind additives.

Table 1 Film strength and frictional coefficients of the lubricant for foil rolling lubrication containing 5% single component additives

No.	Additive constituent	Film strength/ N	Frictional coefficient
1	Dodecanoic acid	320	0. 096
2	Tetradecanol	310	0. 100
3	Dodecanol	290	0. 102
4	Methyl laurate	290	0. 115
5	Butyl oleate	270	0. 105
6	Cyclic ester	230	0. 110

When two or three of the additives metioned above are used combinatively, the film strength of the lubricant is often larger than when single component additives are used independently. Moreover, the compound effects vary greatly with the structural differences of the molecules of the additives, see Table 2. When dodecanol and tetradecanol with straight chains are added combinatively, or methyl laurate and dodecanol with straight chains are added combinatively, the film strength of the lubricant increases and the frictional coefficients decrease, thus the additives display addition effect. By contrast, when the cyclic ester and dodecanol(or methyl laurate) are used combinatively, the ad ditives display synergistic effect. The X-ray

Table 2 Film strength and frictional coefficients of lubricants containing 5% compound additives

No.	Additive component	Film strength/ N	Coefficient
7	Dodecanol+ tetradecanol	300	0.100
8	Dodecanol+ methyl laurate	300	0.103
9	Dodecanol+ cyclic ester	340	0.085
10	Cyclic ester+ methyl laurate	340	0.086
11	Cyclic ester+ dodecanol+ methyl laurate	350	0.084
12	Dodecanoic acid + dodecanol+ methyl laurate	330	0.085

diffraction(Figs. 1, 2) indicates that the area of the diffraction peak of No. 9 lubricant(175 mm^2) is larger than that of No. 8 lubricant(160 mm^2) (spreading on a single crystal silicon flake). This means that the adsorbed layer formed on the metallic(or non-metallic) surface by the combinative additive of dodecanol and cyclic ester is thicker than that by the combinative additive of dodecanol and methy laurate, and the arrangement order between molecular layers are better. Therefore, the non-polar radicals in the additive molecules have great influence on the compound effect of the additives. For the straight chain oily additive, the addition of cyclic chain oily additive will help to obtain significant strengthening effect of the lubricant film.

2.4 *Development of New Additives for Aluminium Rolling Lubrication*

It is very difficult for the existing additives for aluminium rolling lubrication to meet the requirements of lubricity and annealing surface quality simultaneously. In order to resolve this obvious contradiction, based on the study of the compound effect of oily additives principally of physical adsorption, the authors determined the optimized ratios of the components using orthogonal tests. The optimized additive for strip rolling, CSA-SH, and the optimized additive for foil rolling, CSA-FH, not only have good lubricity, but excellent annealing volatility. When they are mixed with home base oils or imported base oils, various kinds of lubricants with good performance for aluminium rolling lubrication can be prepared. Their combination properties reach the world advanced level, therefore they are new ideal lubricant additives for aluminium rolling. The properties of CSA-SH and CSA-FH additives are listed in Table 3.

Fig. 1 X-ray diffraction pattern of base oil containing 5%(dodecanol+ methyl laurate)

Fig. 2 X-ray diffraction pattern of oil containing 5%(dodecanol+ cyclic ester)

3 EVALUATION OF MAIN PHYSICAL AND CHEMICAL PROPERTIES OF CSA-SH AND CSA-FH ADDITIVES

In order to effectively evaluate their physical and chemical properties, the CSA-SH and CSA-FH additives, the CSA-1, CSA-B additives made in China[2] and WYROL$_{12}$, WYROL$_{10}$ additives made by ESSO Company were respectively dissolved into China-made base oils for strip rolling and foil rolling, and then comparison tests were performed.

3.1 *Film Strength*

Table 3 Properties of CSA-SH and CSA-FH additives

Property	CSA-SH	CSA-FH
Appearance	colorless and transparent	near colorless and transparent
Acid value, $KOH/mg\cdot g^{-1}$	≤0.2	≤0.2
Iodine value, $I/mg\cdot g^{-1}$	< 4	< 4
Saponification value/ $mg\cdot g^{-1}$	90~ 100	160~ 190
Hydroxyl value, $KOH/mg\cdot g^{-1}$	180~ 210	125~ 155
Freezing point/ ℃	10~ 11	2~ 3

The pressure which the lubricant film in the deformed zone bears depends upon the deformation drag of the rolled workpiece. If the adsorbed film formed on the metal surface by the polar molecules in the lubricant can bear pressure higher than that produced in the plastic deformation process, then this layer of lubricant film can effectively prevent the rollers from directly contacting with the rolled workpiece and keeps good lubricating state. Therefore, the film strength is an important parameter reflecting the bearing capacity of the lubricant film. The four-ball machine test indicates that the new generation of additives, CSA-SH and CSA-FH, have higher film strength than those of WYROL series and CSA-1, CSA-B, see Fig. 3.

3.2 *Frictional Coefficients and Yields of Abrasive Particles*

The frictional coefficients and the yields of abrasive particles are closely related to the friction state of the friction pairs, and can inherently reflect the lubricity of the lubricants. Table 4 gives the test results of frictional coefficients and yields of abrasive particles obtained from a MRX-200 pin-on-disc wear device. It shows that although the three additives for strip rolling lubrication $WYROL_{12}$, CSA-1 and CSA-SH have similar lubricity, there are evident differences between the three additives for foil rolling lubrication, $WYROL_{10}$, CSA-B and CSA-FH. Not only does the CSA-FH additive have smallest frictional coefficient, but also its yield of abrasive particles is only 43 percent or 52 percent of that of $WRYOL_{10}$ and CSA-B, respectively, therefore, the lubricity of the CSA-FH additive is much better than those of the other additives for foil rolling.

3.3 *Test of Annealing Oil Spots*

In order to meet the needs of practical applications, part of the aluminium materials undergo annealing following rolling, but it is difficult to get rid of oil spots when the aluminium materials are half hard or when the annealing temperature is relatively lower. Therefore, the

Fig. 3 Comparisons of film strength
(a) —additives for strip rolling; (b) —additives for foil rolling

surface quality of the rolled workpiece, especially after annealing, is an important factor judging the quality of the lubricants.

At the present moment, there is no unitary standards for measuring the pollution of the surface of annealed workpieces. For this reason, the authors adopted the internationally universal 6-grade classification method: The higher the grade, the more severe the surface pollution. The results of surface pollution after annealing are given in Fig. 4. It is known that the best annealing surface quality can be obtained by using CSA-SH and CSA-FH additives, and when their contents are smaller than 6 percent, the oil spots can match those produced when only pure base oils are used; $WYROL_{12}$ and $WYROL_{10}$ are next to CSA-SH and CSA-FH; CSA-1 and CSA-B are the third.

3. 4 *Solubility of Additives in Base Oils and Separation Temperatures*

In order to ensure the stable progress of the rolling process, not only are good mutual solubility of additive and base oil needed, but also the additive should not separate from the base oil. The separation of the additive from the base oil will make the properties of the lubricant unstable, thus affecting the normal progress of the rolling process. Table 5 gives the mutual solubility of additives and base oils and the separation temperatures of the additives. The data in Table 5 indicate that CSA-SH and CSA-FH can well adapt to the variations of the ambient temperature, thus ensuring the usability of the lubricants in cold circumstances.

3. 5 *Practical Industrial Applications*

The lubricant for strip rolling prepared using CSA-SH additive and home base oil D_{100} has been on probation on an imported high-speed cold-rolling mill for half a year, and the results are satisfying. This lubricant can not only meet the need for large reduction in process, but also resolve the difficult problem that oil spots are prone to form in rolling the LF21 aluminium alloy, thus reducing the reject rate due to oil spoils by 80 percent.

The applications of the lubricant for foil rolling prepared using CSA-FH additive and home base oil D_{80} on several high-speed aluminium foil mills indicate that the necessary addition amount of the CSA-FH additive is only half of that of the $WYROL_{10}$, and the rolled foils have bright and clean surfaces, higher final product rate and better quality. The rolled 0. 02 mm thick medical aluminium foils have pinholes less than 2 per m^2 and the comprehensive final product rate reaches 90 percent; the rolled 0. 007 mm

Fig. 4 Comparisons of annealing brown spots of several lubricants containing different additives

(a) —additives for strip rolling;

(b) —additives for foil rolling

Table 4 Mutual solubility between several additives and base oils and separation temperautres of additives(5%)

Property	Additive for strip rolling		
	$WYROL_{12}$	CSA-1	CSA-SH
Mutual solubility	excellent	excellent	excellent
Separation temperature/ ℃	− 1	4	− 5

Property	Additive for foil rolling		
	$WYROL_{10}$	CSA-B	CSA-FH
Mutual solubility	excellent	excellent	excellent
Separation temperature/ ℃	− 13	− 10	− 13

thick aluminium foils have pinholes less than 30 per m^2, and the comprehensive final product rate exceeds 82 percent (mainly 0.006 mm thick aluminium foils), therefore the quality and the final product rates of home foils have reached the world advanced level.

4 CONCLUSION

The new generation of lubricant additives CSA-SH and CSA-FH for aluminium rolling lubrication developed by the authors has successfully resolved the contradictions between the lubricity and annealing behavoir. They are superior to the various existing additives for aluminium rolling lubrication, and their comprehensive performance has reached the world advanced level. When added into the home base oils, high quality aluminium strips and foils can be manufactured.

REFERENCES

1 Mao Daheng, Xiao Gang, Cheng Jun. Journal of Central South University of Technology, 1996, 27(3):
2 Mao Daheng, Deng Bailu, Liu Guanglian. Journal of Central-South Institute of Mining and Metallurgy, (in Chinese), 1994, 25(3): 364− 369.
3 Sun Jianlin. Process Technology of Light Metals, (in Chinese), 1990, 18(4): 25− 28.

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