

Development of WFR-3R, Next-Generation Water-Free Die Lubricant and Micro Spray Application

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1. Introduction

In die-casting process, it is important for die lubricant to provide smooth release and prevent soldering problem. 30 years ago, the lubricant had been switched from oil-based type, to water-soluble type, to avoid and control fire danger and environmental hazard caused by oil application.

Currently, water-soluble die lubricant, which oil ingredient is emulsified in water with surfactant, is used widely.

In spite of great feature of water soluble lubricant in safety and environment areas, it creates numerous issues such as 1) water residue reject by application of significant spray amount; 2) metal flow problem due to low die temperature; 3) short die durability caused by rapid temperature fluctuation; 4) increase of soldering problem resulted from poor adhesion efficiency.

In addition to the above, water-soluble die lubricant has been often used for reducing die temperature mainly for adhering die lubricant film. However, it makes die temperature unstable, due to dependency on water evaporation for efficient heat exchange.

Consequently, WFR-3R, the next-generation water-free die lubricant and its application method were developed by utilizing technology of old oil-based die lubricant's excellent performance of creating lubricant film with small amount application and eliminate bad influence of old oil-based die lubricants, for allowing quality improvement, environmental improvement and production improvement.

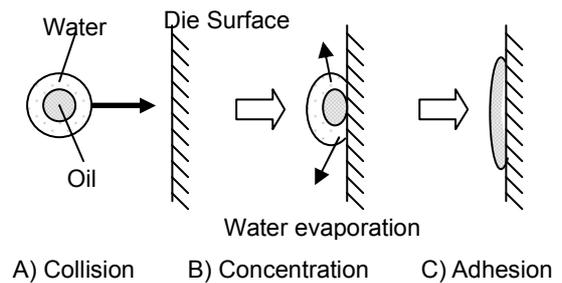
This paper explains about brief overview of this development for lubricant and spray unit.

2. Problems of water-soluble die lubricant

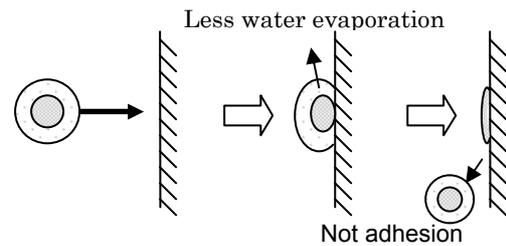
Narrow adequate range of die temperature

As shown in diagram 1, water soluble die lubricant is emulsion type that main active ingredients are included in water. The lubricant adhesion is assumed to occur by collision energy when emulsified particles hit on die surface. Thus, if die temperature is below 150°C, it interferes quick water evaporation during spray application of die lubricant on die surface; hence, the sprayed particles wash out without leaving oil ingredient on the surface after all (diagram 2). On the other hand, if

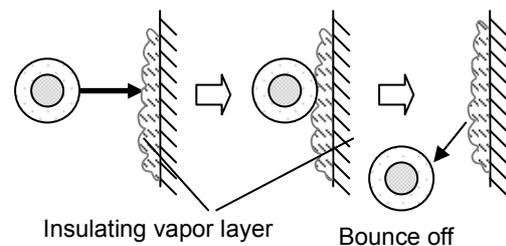
temperature is over 250°C, it causes significant thermal expansion of water evaporated (Leidenfrost phenomenon, diagram 3); creates insulating vapor layer on die surface; finally prevents significant collision energy when lubricant particles stick on the surface.



The diagram 1: Adhesion process of water-based die lubricant



The diagram 2: Reduction of adhesion by low die temperature



The diagram 3: Reduction of adhesion by high die temperature (Leidenfrost phenomenon)

It means that appropriate die temperature should be between 150-250°C during lubricant application, in order to stabilize adhesion efficiency of water-soluble die lubricant. The definition of adequate die temperature in die-casting currently suggested is actually temperature range to secure lubricant adhesion.

Originally, appropriate die temperature can be obtained from balance between high temperatures to extend metal flow range during filling molten metal

into die cavity; low temperature to improve solidification and to prevent soldering problem on die surface. However in application of water-soluble die lubricant, the range of die temperature setting is narrow, in order to stabilize adhesion efficiency of lubricant.

Water residue on die surface

Water-soluble die lubricant reduces die temperature by application of lubricant on die surface, because main content is water. This is also a flexible factor to change die temperature by adjusting spray position and amount.

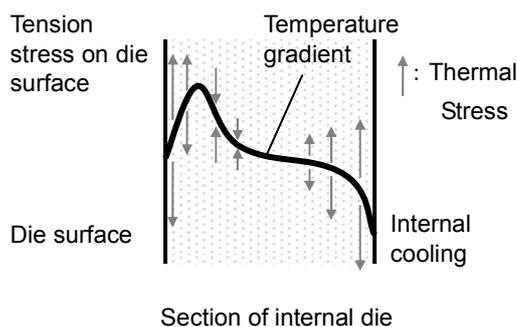
However, excessive application of water leaves water residue on die surface and in gap; cause water inclusion in molten metal during casting; cause porosity problem, water stain on the casting surface.

Especially in vacuum die-casting, water residue in clearance parts of ejector pin or sliding section of core are sucked into cavity; included in metal while expanding, then finally makes serious damage for product quality.

2.3 Thermal stress caused by water soluble die lubricant application on die surface

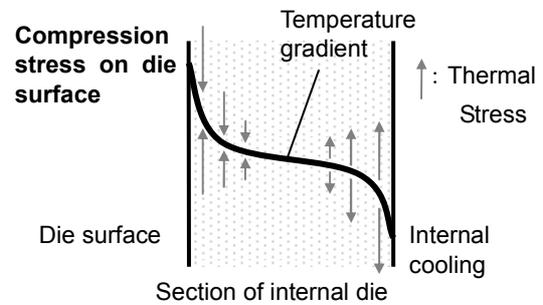
As stated previously, in order to adhere sufficient lubrication film on die surface with water-soluble die lubricant, it is important to reduce die temperature by approximately 200°C. Whereby, additional lubricant may need to be applied; or water may need to be applied onto high temperature area before spraying lubricant.

However, excess water application on die surface can significantly affect on die durability, due to causing great thermal stress, depending on thermal amplitude created. The diagram 4 shows prospect model of thermal stress that occurs inside of die by water application on die surface.



The diagram 4: Thermal stress distribution model & temperature gradient of internal die with application of water on die surface

When surface temperature is reduced lower than internal temperature, it creates stress in direction of tension. If this stress amplitude occurs at every application, eventually it causes cracking defect on die surface. The diagram 5 shows the prospect model of thermal stress that occurs inside of die without water application.



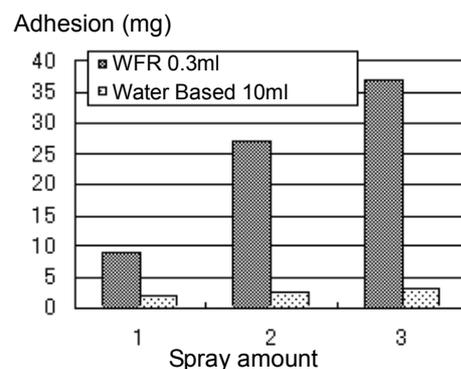
The diagram 5: Thermal stress distribution model & temperature gradient of internal die without application of water on die surface

If no water is applied, surface temperature is always kept higher than internal temperature, only compression stress occurs on the surface. In other words, cracking caused by thermal stress won't be created, when no water is applied on die surface. It also means eliminating compression stresses which breeds cracking.

3. Characteristics of Water Free Releasing agent.

Broad temperature range and high adhesion efficiency

This Water Free die lubricant is composed of 10% of active ingredient for releasing product and specialized refined base oil to control viscosity. In this section, it is explained by comparison with water-soluble die lubricant. The comparison items are A-1609 and WFR-3R, both made by Aoki Science. The diagram 6 shows difference of adhesion efficiency between water-based/ WFR.



The diagram 6: Difference of adhesion by spray amount of water-based/WFR (Trial temperature: 250°C)

In this trial, following amounts of lubricants were used:

Water Free Releasing agent, WFR-3R:

0.3, 0.6 and 0.9ml;

Water-soluble die lubricant, A1609:

10, 20 and 30ml (diluted ratio; 80 : 1)

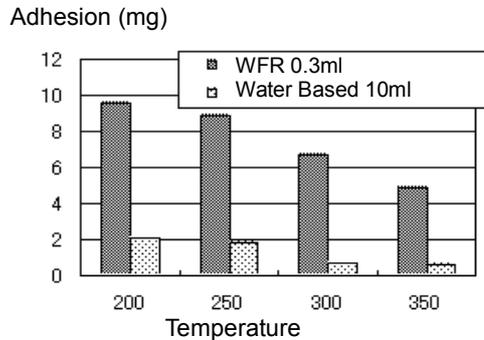
Trial procedure:

1. Apply lubricant on metal plate heated by 250°C

2. Measure adhesion (weight) after it was dried.

As a result, the water-soluble die lubricant showed very little adhesion, in spite of increase of spray amount. On the other hand, WFR-3R performed great adhesion; 30-50% of main ingredients adhered on the plate. Furthermore, spray amount increased; more adhesion also increased on the metal plate.

The diagram 7 shows difference of adhesion by die temperatures, between water-soluble/WFR.



The diagram 7: Difference of adhesion by different temperature for water-based/WFR

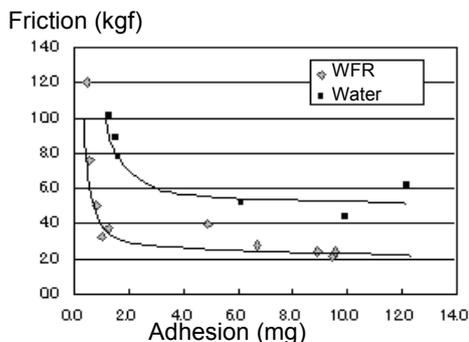
In application of water-soluble die lubricant, when temperature of metal plate became 300°C, adhesion efficiency extremely dropped down by thermal resistance of main ingredient and significant Leidenfrost phenomenon.

Likewise, WFR showed ingredient distraction and decrease of adhesion efficiency in temperature over 300°C. However, as compared with water-soluble die lubricant, it still performed better adhesion in temperature over 350°C.

It means that WFR-3R, Water Free Releasing agent has about 5 times higher adhesion efficiency than water-soluble die lubricant even 1/30 of water-soluble die lubricant's spray amount. The adhesion efficiency can be effective in temperature over 300°C, which is difficult to adhere with water soluble die lubricant.

Low friction resistance

The diagram 8 shows trial result on friction resistance of oil-based/WFR. For this trial, a friction trial machine designed by Toyota was used.



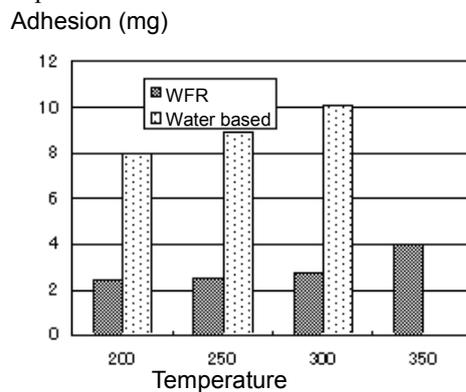
The diagram 8: Relation between friction resistance & adhesion of water-based/WFR

Following trial procedure was carried out to test frictional resistance between water-soluble based/WFR:

1. Apply die lubricant on SKD61(H13) steel plate.
2. Feed 40cc ADC12 molten aluminum, to the lubricated plate and solidify the metal under consistent pressure.
3. Try to release the product by pulling it to the sliding direction.
4. Measure friction

In comparison with water-soluble die lubricant, WFR showed low friction under same adhesion amount. Although the adhesion amount of WFR was only 1mg, friction was half of water-based lubricant. It is assumed to be caused by different ingredients contained in adhesion.

The diagram 9 shows friction resistance on steel plate that is lubricated and heated by different temperature.



The diagram 9: Relation between friction resistance & temperature for water-based/WFR

The conditions used in this trial:

- 10ml of water-soluble die lubricant (diluted by 80 times)
- 0.3ml of WFR

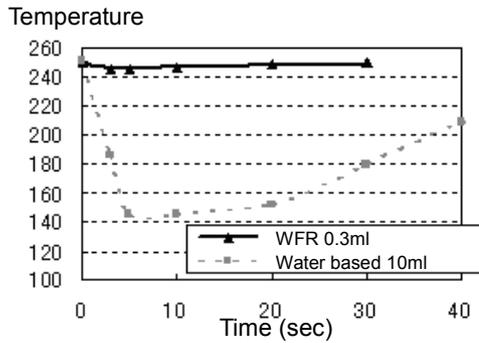
In this comparison, oil-based lubricant showed generally low friction in all temperatures, due to its high adhesion efficiency and low-friction performance of the lubrication film.

In application of water-soluble die lubricant, significant Leidenfrost phenomenon and destruction of main ingredients were observed in temperatures over 300°C. It affected on significant dropdown of adhesion efficiency and increased friction resistance. On the other hand, WFR maintained sufficient low-friction performance, even in 350°C.

WFR-3R, a new oil-based die lubricant has better adhesion ability than that of water-soluble lubricant. Even if adhesion amount is same, friction is small. It means that it can provide excellent release performance with very small spray amount. Also, it performed and secured excellent sliding ability in temperature over 300°C, which is difficult in water-soluble die lubricant.

3.3 Change of die temperature after lubricant application

The diagram 10 shows declining of temperature after spray WFR / water-soluble die lubricants.



The diagram 10: Drop down of die temperature in application of water-soluble/WFR

This data is obtained from lubricated steel plate with thermocouple installed. This plate does not have any internal cooling system like a general die; it shows the re-increasing of temperature by a thermal accumulation of the steel plate.

Water-soluble die lubricants drop down of die temperature and to make a significant heat loss by water vaporization. WFR changed the die temperature very little, due to less volatilization of the base oil. It prevents water stains or cold shut or bad metal flow problems, which are caused by partial dropdown of die temperature. Besides, since there is no heat stress occurred by die temperature fluctuation near die surface, it helps to extend die durability.

3.4 Control of Die Temperature with Cooling Agent

The water free releasing agent, WFR-3R provides smooth release of casting products; prevents soldering defect. Contrary to water-soluble die lubricant, due to very little cooling effect on die surface, it makes significant increase of die temperature.

Nonetheless, since it provides strong lubrication film, therefore soldering defects can be prevented under high die temperature. However, extreme increase of die temperature affects on product strength, which causes of the surface depression by slowdown of solidification speed.

Although it needs to reinforce the internal cooling for WFR application, there are many parts that it may be difficult to have or increase internal cooling pipes because of product configuration and structure. Consequently, it became necessary to apply a method that allows partial reduction of surface temperature, for securing good adhesion efficiency of lubricant.

In general, water is applied on die surface for partial cooling before applying die lubricant, because 1) lubricant does not adhere on the surface under high temperature; 2) lubricant washes out if it's the other way around.

In application of WFR-3R, there is several using application.

1) Spray WFR-3R only, 2) Spray small amount of water or ordinary water based die lubricant before WFR-3R for partial surface temperature reduction where does not have enough inner cooling pipes.

3.5 Painting ability

Water Free Releasing agent, WFR-3R contains silicon to provide sufficient adhesion ability under high temperature. The silicon oil has great water/oil repellent property, therefore it may cause paint peeling and blocky paint finish. In this trial, considering painting ability, WFR-3R contains the paintable silicon oil, which works excellent with paint.

Trial plate used: ADC12 (150 x 70mm);

Trial procedure: Heat trial Aluminum plate by 300°C; provide direct spray lubricants; degrease; paint; dry; print.

Trial assessment: Scratch the trial plate with 10 x 10 squares (at 1mm spacing); apply sticky tape over the scratches and then detach the tape; count squares where paint was peeled off by the sticky tape.

Lubricants	Paint uniformity		Overall	Reference
	Observation	Assessment		Adhesion(mg)
WFR-3R	OK	⊙	⊙	31.5
Water based A	Not uniformed	×	△	7.2
Water based B	Slightly not uniformed	×	×	3.4

Sheet 1: Results of paint trial

The result showed that WFR-3R has an excellent paint performance with paintable silicon oil (almost same result as the one without any application), although adhesion amount is 5-10 times more than water-soluble die lubricant.

3.6 Environmental improvement and cost reduction

When water-soluble die lubricant is used, it is important to provide waste water treatment. As stated previously, in application of WFR-3R, adhesion efficiency will become 30-50%.

Although the base oil is evaporated in atmosphere, the evaporated amount is very negligible due to small spray amount. Therefore, it prevents oil to run into waste water; significantly contributes to environmental improvement. In terms of results, it is able to expect the reduction of waste water treatment cost and manpower.

If water-soluble die lubricant is switched to WFR-3R, it also reduces cost of die lubricant per 1 shot. Currently a spray amount of water soluble die lubricant at Ryobi Shizuoka plant, 1000-2000ml/shot with 800t die-casting machine; 2000-3000ml/shot with 1650t die-casting machine. If it is switched to WFR-3R, it can reduce the spray amount: 1-1.5ml/shot with 800t machine; 2-3ml/shot with 1650t machine.

In comparison between water-soluble die lubricant diluted by 80times and use as a concentrated solution WFR-3R, actual amount of WFR-3R that is used approximate 1/12.5 of water-soluble before dilution.

Although it depends on price setting of lubricant, it can be extensive reduction of lubricant

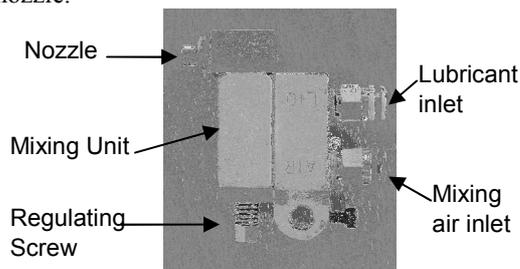
cost. It also contributes to prevent water residue by decrease of die temperature; cold shut, bad metal flow, and to save warm-up shots for starting up production and down time for stopping machine to remove soldering deposits on die; subsequently, to improve product quality and manufacturing ability.

4 Development of small spray application

The Water Free Releasing agent, WFR-3R has very high adhesion efficiency. In order to use this efficiency, technology of micro spray application is required. Our traditional spray systems can not and also do not need to control a few 10ml level. In application of WFR-3R, by calculating from adhesion efficiency rate, approximate 0.3ml/shot for 350t machine; 2ml/shot for 1650t machine are required. Therefore, it is important to control 0.05 ml levels for creating the stable lubrication film for every shot.

Spray Application

For spray nozzle, designed a special spray nozzle called WFS-05G-R for WFR-3R spray application manufactured by Yamaguchi Giken. The diagram 13 shows overview image of mixing nozzle.



The diagram 13: Spray nozzle, WFS-05G-R, by Yamaguchi Giken

There is a taper-cut spool in the mixing unit operates during air pressure, a lubricant circuit is opened.

In other words, based on quantitative adjustment of spray amount by fixed lubricant pressure in preliminary setting, further fine adjustment can also be possible by controlling lubricant pressure.

Low-pressure delivery system for WFR-3R

As previously stated, lubricant pressure can significantly affect on repeatability of spray amount. Furthermore, due to small amount application, pressure must be stabilized as low as 0.03-0.05Mpa.

Since the original solution of WFR-3R is applied, dilution (mixing) equipment is not required. It just needs to deliver WFR-3R from a container to spray nozzle. Usually, diaphragm pumps are used for lubricant delivery to spray unit. However, since WFR-3R requires a small amount application, it will cause pressure difference by pulsation of the diaphragm pumps, even if small type of diaphragm pumps may occur. Therefore, small type of electromagnetic pump was used this time.

WFR-3R is delivered by the pump to a surge tank and stabilizes the delivery pressure, then sent to

the regulating valve. The on/off command for electromagnetic pump is conducted by pressure switch, which is forked from the surge tank. The regulating valve chosen here enabled fine adjustment.

In reduction of delivery pressure with regulating valve, because spray pipes are hermetically sealed, and spray amount per shot is very small, then it is difficult to reduce pressure quickly. In order to prevent such problem, drain circuit was established after the pump to the regulating valve (patent pending).

This delivery system enabled stabilized lubricant pressure from 0.03-0.05MPa.

Entire spray application system

This spray system is composed of a lubricant delivery line and a mixing air line and mixing nozzle. Since mixing nozzle is small size and can be installed anywhere, it enables to install easily on robots or existing spray units. However, since spray amount is extremely small, operation power of spray WFR-3R is also small. Therefore, the distance between nozzle and die surface must be up to approximate 200mm. Furthermore, we must handle carefully about water in mixing airline and contamination in lubricant line.

5. Summary

The Water free releasing agent, WFR-3R and Micro spray application that we developed for this time, it is currently under operation for 350t die-casting machine at Ryobi Shizuoka plant. We improved the internal cooling system of our die for less overheating performance allowed water-less die-casting with only 0.3ml/shot spray amount of WFR-3R.

Without necessity of air blowing cycle, and cycle time was significantly cut downed. Also, without water residue rejects and quick increase of die temperature, warm-up shots for before the production was also saved.

We would like to continue striving for further expansion of this system that allows improvement of quality and production.