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BEHAVIOR OF COLD ROLLING EMULSIONS IN THE OBTAINING PROCESS OF STEEL STRIPS

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ABSTRACT

The research was focused on determining an optimum rolling emulsion to be used on a cold rolling mill from Galfinband Galati Romania. In this plant are obtained steel strips with the thickness of 0.7-0.8 mm. The main parameters depending on which the performance of a lubricant varies were determined. These were: viscosity, pH, thickness of lubrificant film, size of emulsion particles and their distribution on the surface of the steel band, oil content in the lubricating emulsion, usage degree of emulsion, applying method. The characteristics of mineral oil, fresh and recirculated emulsions have been analysed and discussed. Also by macroscopy were analyzed the form of contaminants on the surface of the steel bands which originate from lubricating emulsion. Their appearance is analyzed in the report with their generating processes and the quality of the emulsion.

KEYWORKS: cold rolling, emulsions, characterization, surface defects

1. Introduction

To obtain an increased reduction grade in cold rolling of steel is necessary to continue lubrication in the deformation zone. At the same time, due to the thermal effect of deformation the rolls are heated. Therefore they must be continuously cooled. The operating conditions are secured in most cases by combining a lubricant with a cooling agent, resulting what is called an emulsion. The emulsion is a system consisting of two liquid phases, one dispersed in the other. This is lubricating oil in water emulsion, in which different ingredients are introduced to ensure some characteristics and for improving others. In the case of the cold rolling process, the proper lubrication can facilitate: reduction of the thickness of hot rolled strips at acceptable rolling speed; control of heat losses; corrosion protection of the steel band that will be processed and also of rolling equipment; obtaining of quality surfaces of rolling thin strips.

The lubrication reduces the friction and wear at the interface of work rolls and steel strip surface, by formation a lubricant film. So the friction coefficient at cold rolling process in lubrification condition reaches at values μ ~ 0.05 – 0.10 [1 - 3]. The degree of separation of the roll and strip surfaces depends on the thickness of the lubrificant film formed at interface strip/roll. There are different regimes of lubrication at the interface and the process is conditioned by separate stages of the deformation cycle. Into hydrodynamic lubrication regime (when the strip surface and the rolls surface are completely separated by the lubricant film and so friction and wear drop to a very low level) the film thickness is directly proportional to viscosity of lubricant and the speed of rolling [4, 5].

The friction and lubrication are influenced by a number of parameters such as the properties of the material, finishing grade of the surfaces, temperature, sliding speed, contact pressure, and characteristics of the lubricant [6].

From the point of view of the lubricant and parameters that affected the friction and lubrication, respectively the parameters depending on which varies the performance of a lubricant and the friction coefficient are: viscosity, film thickness of lubricant, the pressure stability, temperature stability, and the additives used.

The chemical nature and concentration of additives are unique, being determined by the specific requirements of each mill [7]. Practically should not be exist not even two rolling lines that exactly use the same lubricating emulsion formulation. The lubricants selection for the deformation of the metal strips should be done by considering some particular factors: applying methods of lubricant; types of additives; corrosion control; cleaning performance and removal methods; compatibility with other lubricants and other oils that were previously applied; post-metal processing operations (such the coating processes for steel sheet and strip); safety in relation to the environment; recycling capacity [6, 8].

There are four major considerations in formulating of lubricants:

- to develop the best combination of chemical substances able to reduce friction and to realize the cooling;
- to use of an optimum amount of lubricant for the working area of milling rolls;
- to ensure the removing of residual residues after heat treatments applied to rolled strips;
- to ensure the best total production cost for the cold rolled steel strip manufacturer;

In accordance the characteristics of an ideal lubricant for cold rolling may result in satisfying the following list of requirements [9]:

- to provide the lubrication so rolling regime allowing the production appropriately sized bands in accordance with the beneficiaries requirements;
- to can be easily and cared for applied;
- do not aggravate the cleaning operations by spreading of surpluses on the rolling equipment;
- do not significantly impair the transfer of heat from the rolls, respectively from steel strip, to cooling medium;
- do not break down or deteriorate during the forming process;
- to be easily removed from the surface of the strip after rolling process;
- to be economical in terms of duration of use (the time until wear).

In this paper were studied some properties of lubrificant emulsion to optimise the rolling performances and the lubrification process.

The results were discussed and compared with the technological emulsion used in present in the cold rolling process of steel bands (with thickness of 0.7-0.8mm) at Galfinband plant.

2. Research and discussion

At the cold rolling mill from Galfinband plant for the preparation of lubricating oil is used an emulsifiable concentrate based on mineral oil blended with bactericide and fungicide agents which ensure a long service life. This oil is used for the preparation of a technological emulsion with good performances for lubrication and cooling in a concentration ranged between 2-5% in water. The concentrated product is a clear brown liquid and the emulsions have a milky white appearance with yellowish tint at high concentrations of oil. From the technological point of view, the amount of emulsion needed in the deformation zone is applied by spraying. This requires a certain viscosity of the emulsion.

The new emulsions with variable content of oil (2.5%, 3%, 3.5%, and 4.5%) in industrial water were prepared and used in experiments. The spraying method was used to apply precise amounts of lubricant to local areas of steel band samples. In all experiments was used on type of water and its quality was verified. This was softened and with a slightly acidic pH (6.5). Also have been tested the service emulsion samples with certain utilisation degrees and contamination. These were extracted from spraying equipments of the rolling line Galfinband plant. The macroscopic aspect of some emulsions tested according to composition and usage degree can be observed in Figure 1. The oil degradation by thermal oxidation leads to the decomposition products formation and the changes of its physical properties such as colour and odour (see Figure 1c and Figure 1d).

a. b. c. d.

Fig. 1. *Aspects of different emulsions tested: a-emulsion 2.5%; b-emulsion 5%; c-emulsion after using period of 10 days; d-emulsion waste*

The viscosity, pH, thickness of lubrificant film, size of emulsion particles and their distribution on the surface of the steel band have been analysed. The thickness of lubricant film at different emulsion concentration was determined using gravimetric standard sized samples and analytical balance. The film of oil was removed with organic solvents. The results are shown in Figure 2. As expected the deposited film thickness depends on the concentration of the emulsion on band and wear it. As the emulsion concentration is higher the larger is the film thickness resulting emulsion.

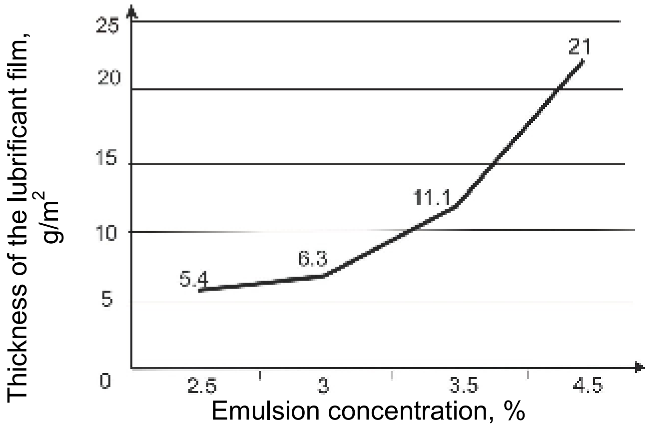


***Fig. 2.** Variation of oil film thickness with emulsion concentration in emulsion samples*

For any lubrication emulsion, the viscosity is considered as the most important parameter. The viscosity of the technological emulsion must resist at action of high pressures occurring during deformation. The coefficient of friction is dependent on viscosity of lubrificant film. An Engler viscometer has been utilising to characterise the viscosity. On this apparatus, the reading is the time t_T (in seconds) required for 200ml of the oil to flow through the device at a predefined temperature T. The conventional viscosity measured in degree Engler (^0E_T). It has been determined by ratio:

$$\text{Viscosity} = \frac{t_T}{C} \tag{1}$$

where C is the calibration constant of the particular viscometer or time (in seconds) required for 200ml of the distilled water to flow through the same device. At temperature of 20^{0}C its value is 58 seconds.

Kinematic viscosity (cSt) can calculated with relation:

$$1^0E = 0.132\text{cSt} \tag{2}$$

The viscosity of oil, fresh emulsions 2.5% and 4%, and the emulsion sample collected after an using period of 10 days were determined (Table 1). For each sample three determinations were made and then an average value of time for leakage was established

***Table 1**. Viscosity for different sample of emulsion sorts, respectively for oil*

Sample	Leakage time* (s)	Conventional viscosity (^0E_T)	Kinematic viscosity (cSt)
Fresh emulsion 2.5%	58.33	1.006	0.133
Fresh emulsion 4%	59.66	1.029	0.136
Emulsion sample after an using period of 10 days from Galfinband	60	1.034	0.137
Oil	890	15.345	2.03

*average value of three measurements

It can observe that viscosity does not vary greatly with the oil concentration in studied emulsion. Viscosity is more influenced by ageing process of emulsion and its contamination.

The increasing of the viscosity is significant in relation with the usage degree of emulsion. A using period of 10 days can be recommended. After this working period, the viscosity will be deteriorated significantly due to increasing of emulsion contamination.

The pH of emulsion influences the lubrificant stability and the process of residues formation on the steel surface. Also pH can affects the particle size of emulsion droplets.

A laboratory electronic device was used for measuring the pH. The results are given in Table 2.

***Table 2.** pH of materials used in experiments*

Sample	Fresh emulsion 2.5-3%	Fresh emulsion 4%	Emulsion after an using period of 10 days	Oil	Water	Emulsion waste
pH	6.5	6.8	7.5	8.5	6.0	8.0

As shown by the results presented in Table 2, the chemical reactions undergone by rolling oil change the pH of samples. The emulsion used in the deformation process must ensure the formation of a continuous film on steel strip surface, resistant to high pressure applied and to temperature developed in the rolling process.

The film formed on steel samples was examined. Images of oil emulsion deposited on steel support are presented in Figure 3.

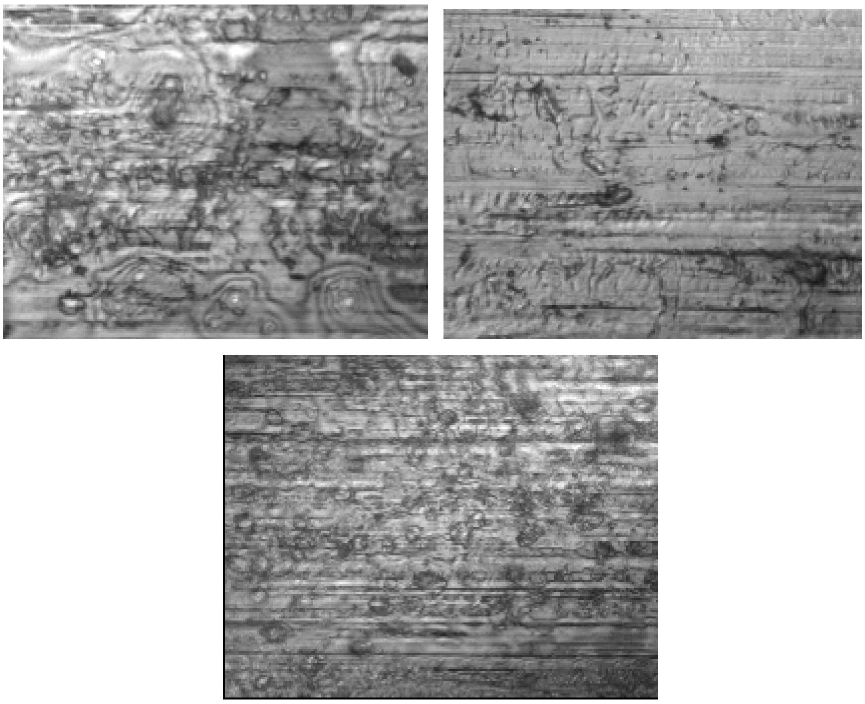
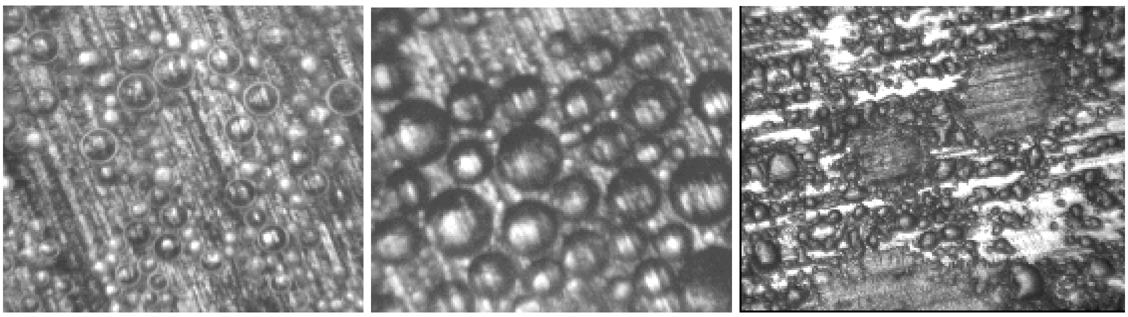


***Fig. 3.** Aspects of emulsion film applied on steel band surface (x400)*

Oil in water emulsion consists of a discontinuous oil phase and a continuous water phase. At applying of emulsion film by spraying the emulsion droplets on steel surface were forming.

Their sizes and distribution were determined by optical microscopy. Figure 4 show that the emulsion droplets have a distinct sizes and different distributions depending on the characteristics of the emulsion.



a. b. c.

***Fig. 4.** Emulsion droplets on surface of the steel specimens (x400): a-emulsion after an using period of 10 days; b-emulsion 3%; c-emulsion 5%*

The size of emulsion particles and their distribution are different because these are influenced by the emulsion quality.

The emulsion 3% presents oil droplets uniform dispersed and larger. Such emulsion is known as „loose" emulsion [10]. Contrarily, at increasing of oil content in lubrificant emulsion the particles sizes were modified.

In generally, is can considered that the emulsion 5% presents droplets that can be fitted into two dimensional classes. Some are larger and mostly smaller.

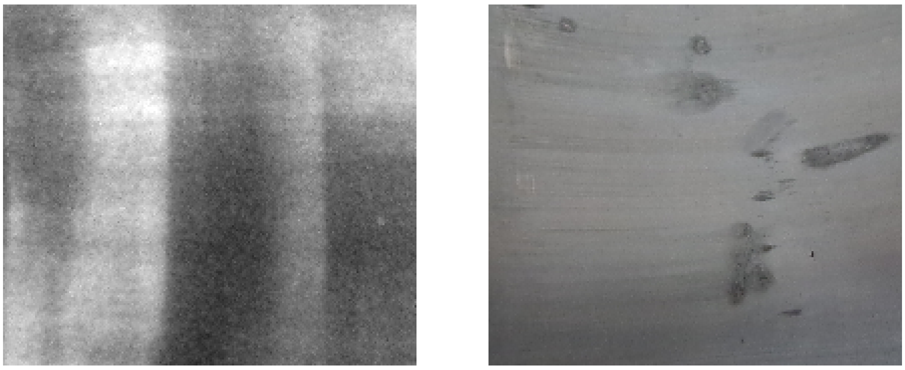
Also these droplets tend to form conglomerates. This emulsion can be classified as a „tight" emulsion [10]. The working time of 10 days bring modifications in the emulsion. Less droplets of usage emulsion (extracted from spraying equipments of the rolling line Galfinband plant) with medium sizes can be observed on surface of the steel specimens.

Part of oil emulsion was destroyed by oxidizing during rolling process. So have been formed carbonaceous residues and contaminants that adhere to the steel surface after rolling. Quality requirements of cold rolled strips impose to lubricant emulsion to generate a minimum amount of such carbonaceous products.

The organic residues on the surface of cold rolled thin strip coming from the following [7]:

- contaminants in the form of soaps or "tramp" oil contaminants such as hydraulic and bearing oils leaked from the rolling mill;
- decomposition products during oil storage and re-circulation;
- contaminants from oil decomposition during the rolling process itself.

The oil impurities, called oil contaminants, cause problems during all stages of the process for obtaining coated plates. Firstly they lead to a decrease in lubricating performance during the rolling process. The contaminating oils ("tramp" oils) should be kept to negligible levels, <0.25%. On the steel strips from Galfinband, black visible traces forming broad bands or stains in rolling direction remain after cold rolling process (Figure 5). The presented specimens have been extracted from steel strips rolled with an emulsion that had a working time of 10 days. The amount of organic residues extracted from the surface of samples analysed has been evaluated by the typical tests "tape test", where contaminants particles on the steel surface are removed using a piece of tape. A residues amount of 8 mg/m^2 was resulted after analysing of 10 samples.



a. b.

Fig. 5. *Macroscopic appearance of the strips surface at the exit of the rolling mill (x400): a- carbonaceous residues arranged in bands; b- carbonaceous residues stains*

An increase in residue levels was attributed to surface reactions between the oil and iron in form of the iron fines resulted from high levels of wear during the rolling process. Also the oil ingredients and tramp materials with high volatilisation temperatures contributed significantly to residue levels. During thermal treatment, the residual contaminants further react with: the volatile products resulted from chemical reactions of remanent rolling oil developed at temperature of thermal treatment); gaseous atmosphere from the treatment furnace; steel strip surface. The contaminants contribute to formation of areas with high carbon level on surface of steel strips following the annealing process (Figure 6).

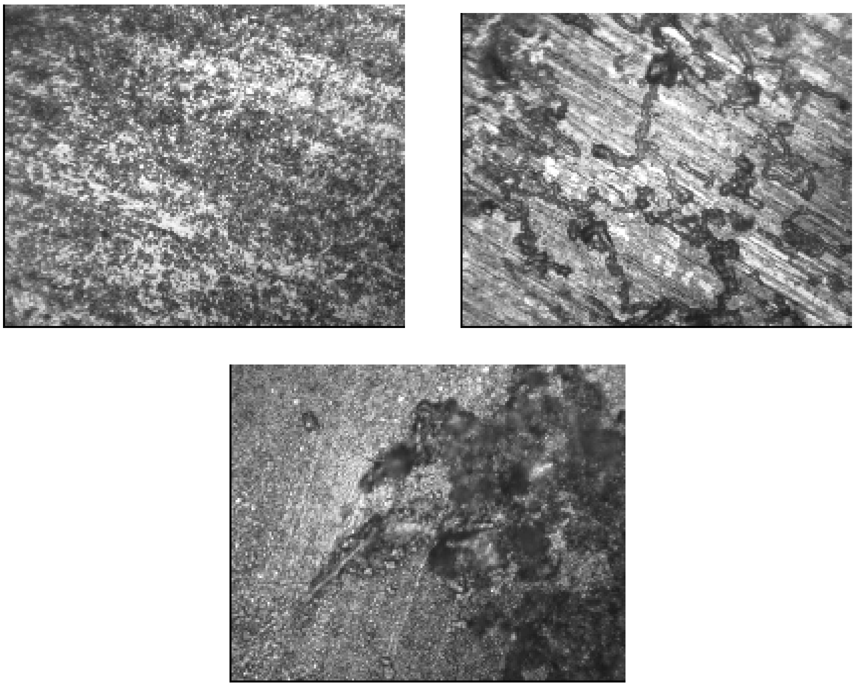


Fig. 6. *Emulsion burned on the surface of band thermal treated (x400)*

In Figure 7 are showed a clean surface (a) and a contaminated surface (b) after applying the same cleaning process as a result of the presence of emulsion burned.

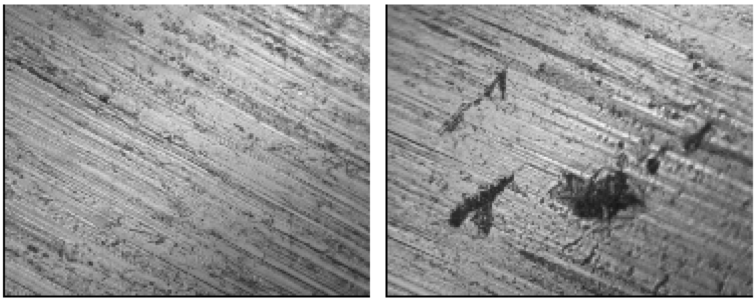


Fig. 7. *Images of steel strips surfaces after applying the cleaning process: clean (a) and contaminated (b) (x400)*

3. Conclusions

An effective lubricant system must ensure in couple steel band-rolls of milling equipment a balance between cooling and lubrication. From the point of view of the lubricant and friction, there are many parameters that affect the lubrication.

The viscosity, pH, thickness of lubrificant film, size and distribution of emulsion particles on the surface, oil content in the lubricating emulsion, usage degree of emulsion, applying method are important parameters that demonstrate the performance of a lubricant.

These have been studied in this paper. Also, the presence of contaminants and residues on the steel strips surface was analysed and put in relation with the lubrication system utilised in the cold rolling process.

The oil film thickness applied by spaying is directly proportional to the viscosity of the emulsion. In correlation with the literature is recommended the emulsions with maximum 3.5% oil.

The increasing of the viscosity is significant in relation with the usage degree of emulsion. As result a working period of 10 days can be recommended.

For the samples analysed the size of emulsion particles and their distribution are different. These are influenced by the emulsion quality and the working period. The carbonaceous residues that remain on the surface of the strip after rolling must strictly limited because have a negative influence in all subsequent stages of processing.

Research has shown that increasing the degree of contamination of the emulsion by recirculation and wear can generate an amount of carbon residue up to 8 mg/m^2.

During the heat treatment, residual products is reacted further with the gaseous products, furnace atmosphere and with the surface of the steel strip and cause the formation of areas with high carbon concentration on the surface of the strip subjected to the annealing process.

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