INFLUENCE OF INHIBITORS IN COOLING EMULSION UPON MAIN CUTTING FORCE AND CORROSION OF WORKPIECE

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Abstract

Cooling emulsions (agents for cooling, rinsing and lubricating) are used during fabrication of machine parts applying particle-removing processes, but their anticorrosion action is also important. Effects of different inhibiting emulsions upon main cutting force at turning of carbon steel as well their influence upon corrosion resistance of a part are reported in the contribution.

Main cutting forces are measured applying dynamometric device when inhibiting emulsions have been used, and compared with data obtained at dry machining. Efficiency of inhibitors has been evaluated applying electrochemical and corrosion tests in salt and humid atmosphere. Corrosion behavior has been monitored in atmospheric conditions and in sealed space.

Results of conducted research indicate that application of inhibiting emulsions as coolants may significantly reduce cutting forces and slow down corrosion rate for tested carbon steel grade.

1*. Introduction*

Modern machining operation must provide, besides quality machining, also a number of other properties to satisfy market requirements. Expanding trend in production is application of cooling, flushing and lubricating agents (SHIP), which will provide, beside mentioned characteristics, also feasible bio-degradation capability and corrosive protection [1]. However, primary features of cooling and lubricating capability are taken as granted.

Corrosive protection must be effective during the machining process and afterwards, when parts are moved to subsequent machining operation on other machines or waiting for assembling operation. Application of SHIP coolants eliminates need for additional corrosion protection (either temporary or long-termed protection). Such protection is particularly appropriate when parts are waiting for transportation, next operation or assembling [2].

Corrosion properties are also important from the standpoint of tooling machines used in machining process. Protection provides easier maintenance and cleaning of machines, and extended service life of machine parts may be expected. Inhibitors are used in almost all industrial fields. Corrosion of metals is a complex and heterogeneous process because of many anodic and cathodic points on the surface. Inhibitors that are available at such locations, impede electrochemical processes or transport of reactive products from the solution [3]. After Rosenfeld and coworkers, inhibitors generate protective barrier between metal and corrosive agent, by incorporating into the surface film of corrosion products. French and coworkers demonstrated SEM results, where the structure of corrosion products is modified by inhibitors. They made conclusion that structure of inhibitors should be in compliance with structure of corrosion products. Thus, certain inhibitors may be effective if corrosion products are iron carbonates or sulfides, but not if products are oxides [4]. Inhibitors most frequently used in coolants during machining are compounds containing nitrogen, such as amines, amides, etc. They are generally adsorbed at the surface of metal, blocking active points or making a physical barrier which reduces transportation of corrosive agents to the surface of metal [5]. Organic inhibitors used for protection against corrosion induced by oxygen, produce adsorbed films, providing protection of steel surface. They are adsorbed to the steel surface, producing mono- or two layer structures, ranging in thickness between 3 and 10 nm. They are composed of surface-active molecules, and polar main group containing cation group with nitrogen. Also, inhibitors containing sulfur or phosphorus in main group are used. Such molecules, due to hydrophobic effect, have strong tendency of forming adsorbed films.

2. *Experimental work*

Effect of SHIP coolants containing different types of inhibitors upon cutting force and corrosion behavior of machined parts are tested, and compared to the case of dry machining. For testing following SHIP coolants were used: EcoLine Cutting Fluid (**INH1**), coolant containing VCI-345 inhibitor (**INH2**) and coolant containing BU-7 inhibitor (**INH3**). Testing and measurements have been conducted applying conventional lathe of TES-3 designation. For testing, samples have been machined from grade ISO 360 B steel, with guaranteed chemical composition and mechanical properties. Machining parameters were as follows: cutting depth a_p = 1 mm, feed per revolution 0,2 mm, cutting speed v_c=45 m min^{-1} at n=850 min^{-1} (selected from the lathe gear box). Sketch of the sample and clamping arrangement is presented in Fig.1. All samples have been turned to diameter of 17 mm at length of 50 mm in first step, and than testing was made in second operation, while turning samples to diameter of 15 mm at length of 50 mm. Dotted line indicate final shape of machined sample. Samples have been machined applying same type of tool tip.

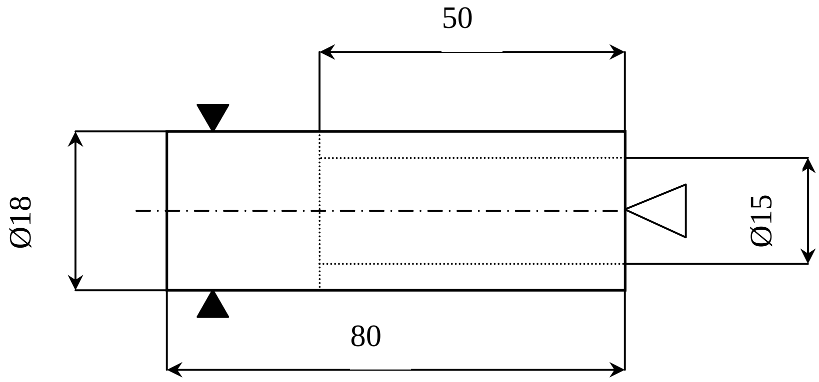

Figure 1. Shape and dimensions of sample, clamping arrangement

Subsequent to machining, corrosive effects of SHIP coolants containing inhibitors 1, 2, and 3 were tested in salt and wet chamber, in atmospheric conditions and closed area, and compared to the case of dry machining. Testing of corrosion rate and SHIP coolant anticorrosion efficiency have been conducted applying electrochemical method of quasi-potentiostatic polarization through recording *E-j* polarization curve (method of Tafel extrapolation).

3. *Results and discussion*

3.1. ***Measurement of cutting force***

For measurement of cutting force during machining, for both cases when SHIP coolants were used and for dry machining, three-component dynamometer device has been used. It was fixed to the lathe support and it was holding turning tool. For each sample, three components of cutting force have been measured:

1. Fz=Fc main cutting force
2. Fx=Ff feed cutting force
3. Fy=Fp reverse cutting force

Magnitude of cutting force was calculated applying expression 1.

$$F_r = \sqrt{F_x^2 + F_y^2 + F_z^2} \text{ [N]} \qquad (1)$$

For each SHIP coolant containing inhibitor, three measurements were made, and mean value for given measuring interval has been used in analysis. Mean value of resulting cutting force given in order from least to greatest are listed in Table 1

Table 1. Mean value of cutting form for tested SLIP coolants containing different inhibitors

No.	Inhibitor	Force [N]
1	INH1	**761**
2	INH2	**748**
3	INH3	**776**
4	Dry machining (reference)	**813**

Measurement of main cutting force indicated that they can be significantly reduced if SHIP coolants containing inhibitors are used. Moreover, it is revealed that there is a significant variation between in force magnitude when different coolants have been used during machining. Measured data indicate that lowest value of cutting force at constant cutting conditions are attained with SHIP coolant containing INH2 inhibitor.

3.2. Testing of inhibitor efficiency upon corrosion protection of machined part

Testing of the inhibitor efficiency in affecting corrosion rate of machined parts compared to the case of dry machining is conducted one day after machining, in the meantime samples being conditioned in closed area. Testing has been done in salt chamber applying 5% NaCl solution till the occurrence of corrosion signs, wet chamber, atmospheric conditions and in closed area. Each set of samples was tested in same conditions, as follows: in salt chamber for 2 hours, in wet chamber for 24 hours and in atmospheric conditions and closed area for 30 days.

Appearance of samples machined without application of SHIP coolant (dry machining) is given in **Fig.2**.

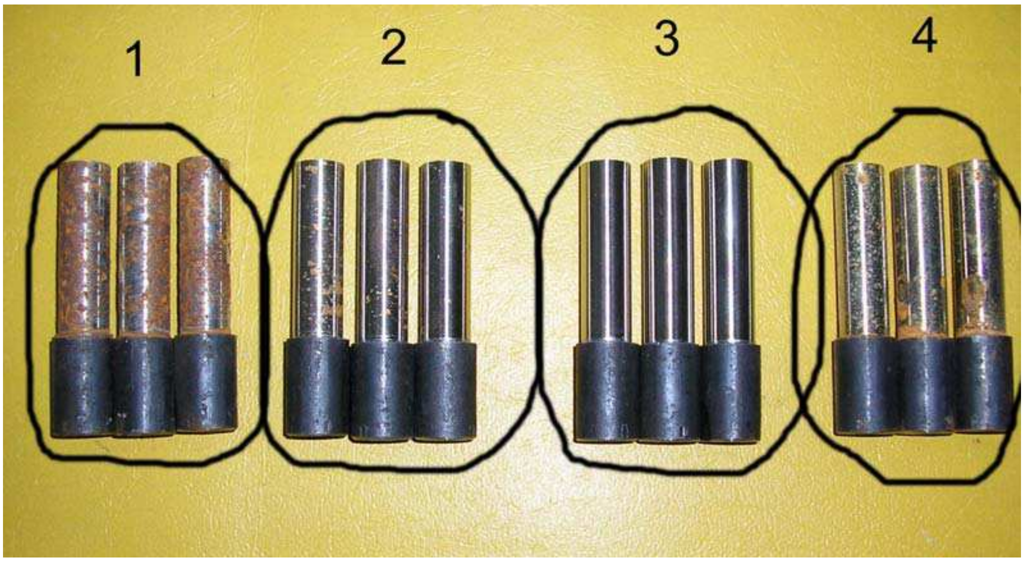

Figure 2. Appearance of samples machined without application of coolant (dry machining) after testing: 1-in salt chamber, 2-in atmospheric conditions, 3-in closed area, 4-in wet chamber.

Appearance of samples machined with application of SHIP coolant containing inhibitor INH1 is given in **Fig.3.**

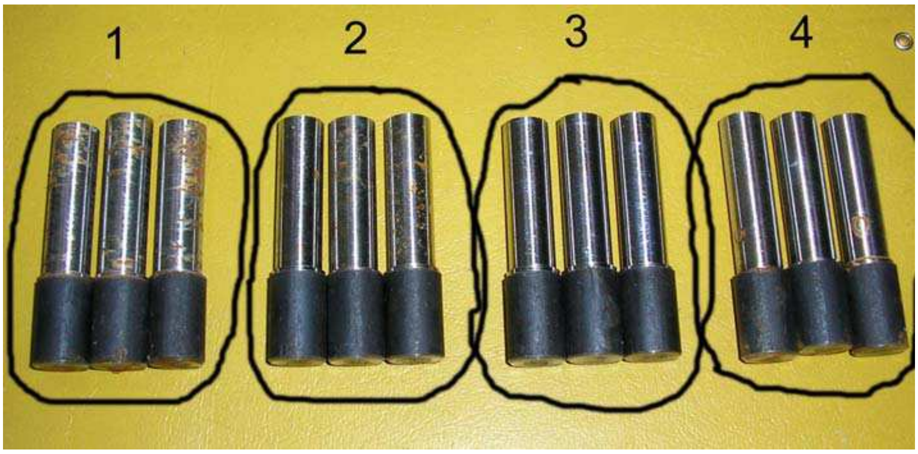

Figure 3. Appearance of samples machined with application of SHIP coolant containing inhibitor INH1 after testing 1-in salt chamber, 2-in atmospheric conditions, 3-in closed area, 4-in wet chamber

Appearance of samples machined with application of SHIP coolant containing inhibitor INH2 is given in **Fig. 4**.

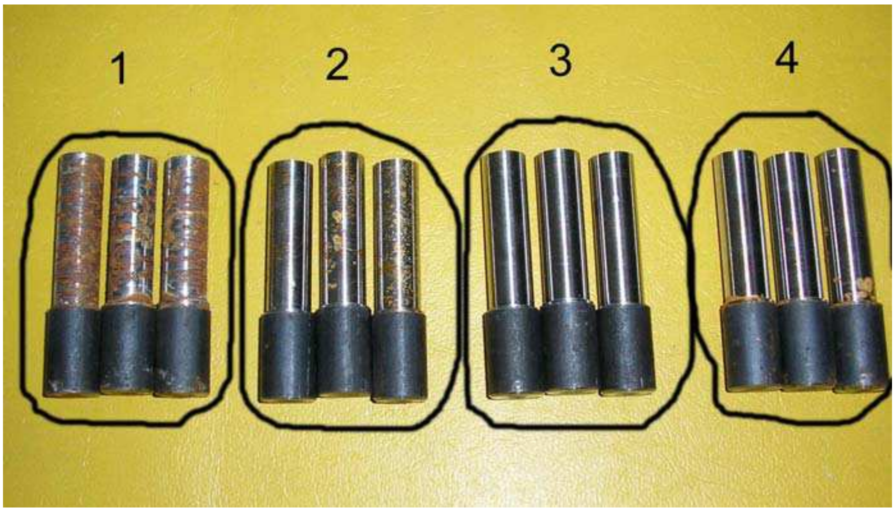

Figure 4. Appearance of samples machined with application of SHIP coolant containing inhibitor INH2 after testing 1-in salt chamber, 2-in atmospheric conditions, 3-in closed area, 4-in wet chamber

Appearance of samples machined with application of SHIP coolant containing inhibitor INH3 is given in **Fig. 5**.

Figure 5. Appearance of samples machined with application of SHIP coolant containing inhibitor INH3 after testing 1-in salt chamber, 2-in atmospheric conditions, 3-in closed area, 4-in wet chamber

Salt chamber, being most aggressive environment, showed first results of corrosion after 2 hours testing, while in wet chamber corrosion occurred after 24 hours exposure.
It is important to notice that samples stored in closed area have not signs of corrosion in this time range.

3.3. Electrochemical testing of inhibitor efficiency

Testing of corrosion rate and efficiency of SHIP coolants containing inhibitors was conducted applying electrochemical method of quasi-potentiostatic polarization, i.e. applying Tafel extrapolation. Applying method of quasi-potentiostatic polarization, recording of polarization curves in range of -250 mV to +150mV from corrosion potential E_{cor}, at potential change rate of 0,1 mVs^{-1} was made, following parameters were calculated: corrosion potential E_{cor} , density of corrosion current j_{cor}, slope of Tafel lines b_a and b_k and efficiency of inhibitor Z. Also, effect of coolant flow rate upon efficiency of inhibitor has been tested. Surface of operating electrode was 1 cm^2.

Figures 5 and 6 depict polarization curves for carbon steel in coolants that contained 1 ml of inhibitor in comparison with solution not containing inhibitor, but including case of stagnant coolant and simulation of coolant flow. Kinetic parameters determined applying Tafel method of extrapolation are given i Table 2.

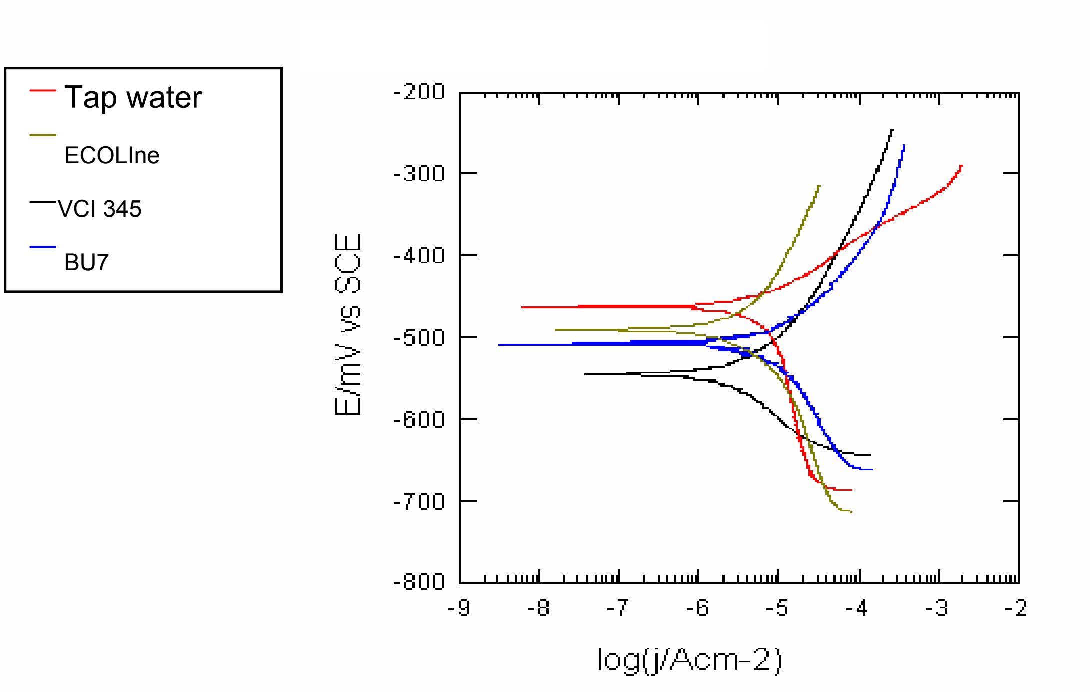

Figure 5. Polarization curve for grade ISO Fe 360 B steel in agitated coolant with and without added inhibitor

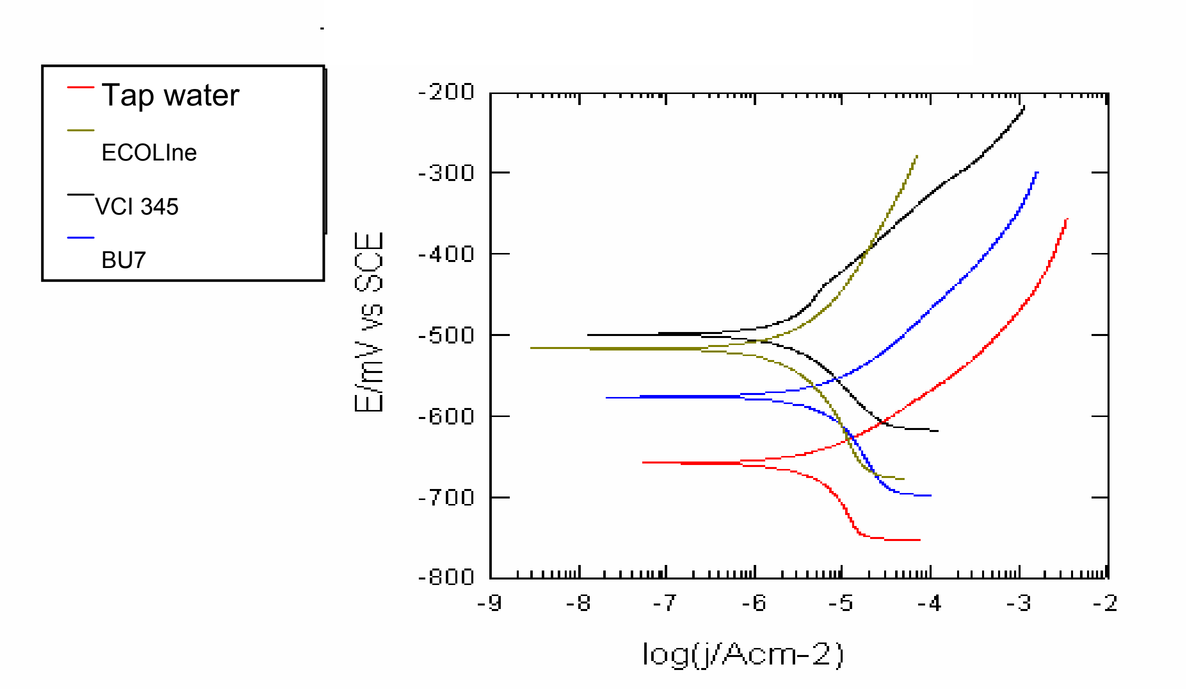

Figure 6. Polarization curve for grade ISO Fe 360 B steel in stagnant coolant with and without added inhibitor

Table 2. Corrosion parameters for carbon steel in tap water with and without added inhibitor

Solution	E_{kor}/ mV vs SCE	b_a/mVdek^{-1}	b_k/mV dek^{-1}	j_{kor}/μAcm^{-2}	v_{kor}/mmg^{-1}	Z , %
INH1 agitated	-433	168	129	3.76	0.043	67.8
INH1 stagnant	-507	156	195	6.57	0.076	16.7
INH2 agitated	-465	233	365	6.68	0,077	42.8
INH2 stagnant	-529	212	251	6,66	0.077	15.6
INH3 agitated	-450	132	144	4.47	0,052	43.3
INH3 stagnant	-548	191	370	6.78	0.078	41.9
No INH agitated	-550	72	416	7.89	0.091	-
No INH stagnant	-620	96	1069	11.68	0.135	-

Recorded data indicate that agitation of electrolyte which was used to simulate coolant flow during machining reduce corrosion rate. Corrosion current is of higher value for systems without electrolyte agitation. E_{cor} is shifted to more positive value when compared with values for systems containing stagnant electrolyte. Efficiency of all three tested inhibitors is better in agitated electrolyte.

4. Conclusions

- Target of the experimental work was to test efficiency of inhibitors used in SHIP coolants upon corrosion of machined parts and magnitude of cutting force. Three inhibitors were tested: EcoLine Cutting Fluid (INH1), VCI-345 (INH2) i BU-7(INH3).
- Results of cutting force measuring indicate that application of coolants containing inhibitors can significantly reduce forces. Lowest force has been obtained when INH2 inhibitor was used (748 N).
- Testing of corrosion properties has been conducted on samples that were machined applying coolants containing inhibitors and without inhibitors by exposing them in salt and wet chamber, in atmoshpehric conditions and in closed area. Also, electrochemical testing has been conducted aplying method of linear polarization (Tafel extrapolation).
- Salt chamber test indicated the best protection against corrosion for samples treated with SHIP coolant containing INH1 inhibitor. Explanation for such results is very good resistance of this coolant against washing-out and agresive environment, since resistant film on metalic surface is formed.
- Testing made in wet chamber indicated best corrosion resistance for samples treated wtih SHIP coolant containing INH1 inhibitor. Samples did not corroded in wet atmosphere.
- Testing i atmospheric conditions and closed area showed equal efficiency of all tested inhibitors

– Results obtained applying Tafel extrapolation indicate that all three inhibitors have better performance in agitated coolant than in stagnant. Descending erformance order of tested inhibitors is as follows : INH1 > INH3 >INH2

5. References

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