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MOGUĆNOST PRIMJENE ČISTIH ULJA ZA OBRADBU METALA PRI HONANJU KOŠULJICA CILINDARA

Sažetak

Honanje ili vlačno glačanje je postupak kojim obrađujemo najfinije površine metala radi postizanja zahtijevane točnosti i kvalitete obrađenih površina. Samo honanje kao i procesi struganja, glodanja, brušenja, tj. rezno uobličavanje metalnih materijala u svom se djelovanju ograničava na relativno tanak površinski sloj izratka i uglavnom izaziva hladnu plastičnu deformaciju, ali ne utječe dalekosežno na strukturu i svojstva materijala.

Pri izvođenju procesa honanja vrlo je bitno da se radna površina oplahuje znatnim količinama sredstava za hlađenje i podmazivanje. Radnu površinu valja hladiti da ne bi došlo do promjene strukture zbog procesa rekristalizacije i otpuštanja. Osim toga, ispiranjem se odvodi metalna prašina nastala honanjem te iščupana zrnca s bruseva. Danas su istraživanja na ovom području usmjerena na primjenu novih sredstava za hlađenje i podmazivanje.

Na temelju ekonomske i ekološke analize i analize kvalitete postupka honanja pri primjeni sredstava za hlađenje i podmazivanje na osnovi mineralnih ulja i uz sadržaj različitih tipova aditiva, u radu je ispitivana mogućnost primjene novih ulja pri honanju košuljica cilindara.

1. Uvod

Košuljice cilindara s obzirom na ponašanje u radu i njihov vijek trajanja moraju ispunjavati vrlo visoke zahtjeve. Uz precizne tokarske strojeve i rezne alate, tehnikama grube obradbe, završne obradbe i honanja postiže se precizna površina košuljica cilindara i fine tolerancije.

Honanje ili vlačno glačanje je takav postupak kojim obrađujemo najfinije cilindrične površine radi postizanja zahtijevane točnosti i kakvoće obrađenih površina, u našem slučaju radnu površinu košuljice cilindra [1].

Samo honanje kao i procesi tokarenja, glodanja, brušenja, tj. rezno uobličavanje metalnih materijala u svom se djelovanju ograničava na relativno tanak površinski sloj izratka i uglavnom izaziva hladnu plastičnu deformaciju, ali s naglaskom da ne vrši dalekosežan utjecaj na strukturu materijala, a time i na svojstva materijala [2].

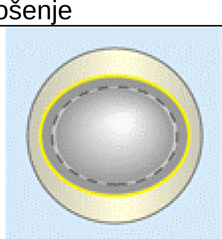
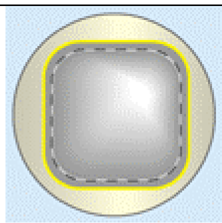
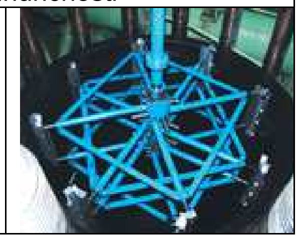
Švedska tvrtka, međunarodno prepoznatljiva, Chris-Marine, oslanjajući se na vlastita višegodišnja iskustva (više od 40 godina) te uz čvrstu suradnju s vodećim proizvođačima motora, specijalno dizajnira visoko kvalitetnu opremu za održavanje dizelovih postrojenja, uključujući i izradu strojeva za honanje. Koristeći takve strojeve za specijalnu obradbu ostvaruje se poboljšanje radnih svojstava dizelovih motora, smanjuje se trošenje kliznih površina košuljica cilindara te se ostvaruju važne uštede u troškovima rada.

2. Razlozi honanja

Prvi cilj honanja je produljenje radnog vijeka košuljica cilindara i klipnih prstena. Radna stanja motora često rezultiraju u povećanju trošenja radne površine košuljica cilindra te oštećenih i slomljenih klipnih prstena. Danas motori mogu raditi s prosječnom temperaturom radne površine košuljice 250 ^{0}C, a kao posljedica toga je da su klipni prsteni podvrgnuti većim radnim silama, što može brzo rezultirati prekomjernim trošenjem košuljice cilindra [3].

Zbog navedenog, nesavršenosti klizne površine košuljica, uzrokovane tom sredinom odnosno trošenjem (slika 2a), mogu biti ispravljene i spriječene honanjem. Jedinstvenim opružnim napinjanjem, honing glava Chris-Marine stroja za honanje poboljšava mjere košuljica formirajući kružni oblik iz ovalnog (slika 1) ili inače potrošenih košuljica. Istodobno stroj također brusi radnu površinu košuljica cilindra radi ostvarivanja ispravne hrapavosti i izmrežene radne površine (slika 2b).

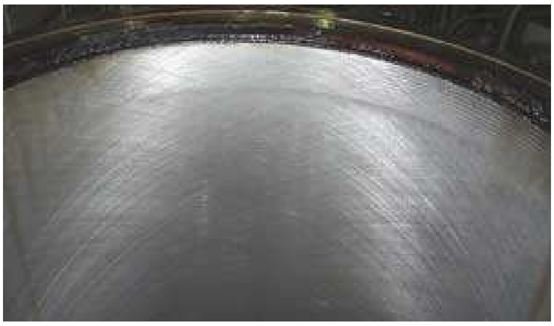
Slika 1: Prikaz dvaju tipova glava stroja za postizanje cilindričnog oblika

4 ruke tip S, za standardnu obradbu, za ovalno istrošenje		8 ruku tip S2, za više različitih istrošenja i necilindričnosti	
			

Drugi razlog honanja je smanjenje rizika od propuštanja kompresije, trošenja i zaribavanja. Glavni problem jajolikosti i trošenja u gornjem dijelu košuljica zbog rada može biti ispravljen honanjem. Honanjem se osim toga ostvaruje izmrežena radna površina, što je u skladu s preporukama proizvođača motora. Takva izmrežena radna površina služi za lakše održavanje tankog uljnog sloja između košuljice cilindra i klipnih prstena te time značajno poboljšava smanjenje trošenja klipnih prstena i znatno smanjuje utrošak ulja za podmazivanje.

Slika 2a: Površina košuljice cilindra prije honanja

Slika 2b: Površina košuljice cilindra nakon završetka honanja



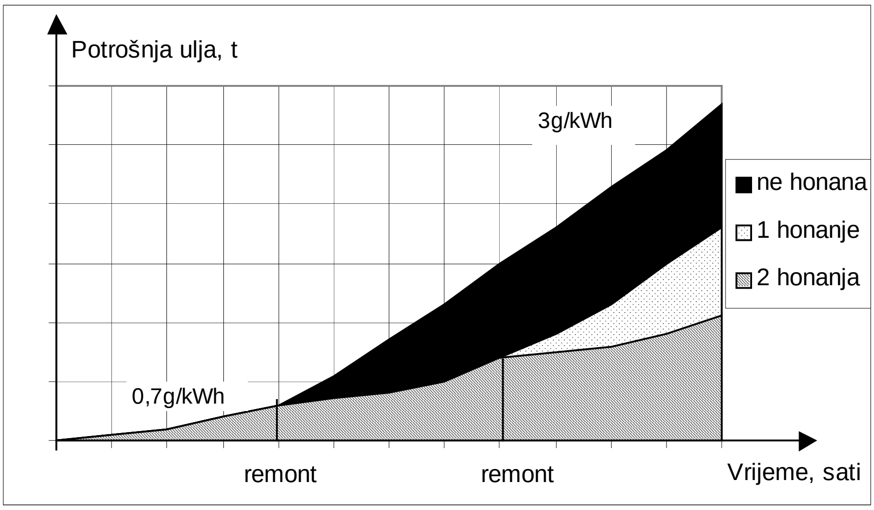
Treći razlog honanja je smanjene utroška ulja za podmazivanje. Na slici 3 prikazana je potrošnja ulja za podmazivanje honane i nehonane košuljice cilindra, 4-taktnog dizelovog motora izlazne snage 10000 kW [4]. Vidljivo je da je potrošnja ulja znatno manja ukoliko se površina košuljice obradbi honanjem pri redovitom servisu motora (remontu).

Primjer shematskog prikaza potrošnje ulja:

- Redovito honana košuljica: 0,7 g/kWh x 10,000 kW x 6,000 h = 42 t/godinu
- Nehonana košuljica: 3 g/kWh x 10,000 kW x 6,000 h = 180 t/godinu.

Ostatak izgaranja u cilindru utječe na naslage na kruni klipa te u radu klipa, kretnji od gornje do donje mrtve točke, može uzrokovati okomite rezove, kanale na košuljicama cilindra. Honanjem preko navedenih kanala i ostalih nepravilnosti ostvaruje se normaliziranje potrošnje ulja za podmazivanje. Zbog toga klipni prsteni ne trebaju nikada biti zamijenjeni u klipu, a da prije nije izvršeno honanje košuljica cilindra.

Slika 3: Prikaz potrošnje ulja uz nehonanu i redovito honanu košuljicu motora



3. Proces ispitivanja

3.1. Stroj za honanje

Istraživanje je provedeno u radnoj prostoriji tvrtke Ivis Marine u sklopu brodogradilišta Viktor Lenac Rijeka (slika 4). Honanje košuljice cilindra motora Sulzer Z 40/48 vršilo se strojem za honanje proizvodnje Chris-Marine, Švedska, tip LB2 [5] i honing glavom stroja S2 31/49 (slika 5).

Brusevi su u glavi stroja za honanje radijalno podesivi preko zupčaničkog prijenosa pa se tako može u uskim granicama mijenjati izmjere, poboljšavati geometrijski oblik (jajolik u cilindrični) i profiniti obrađena površina provrta.

Proces honanja prilikom ispitivanja svakog od sredstava za hlađenje i podmazivanje podijeljen je u tri dijela [6,7,8,9].

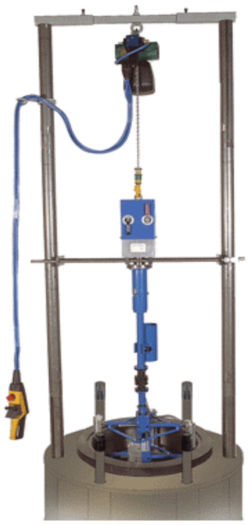
1. Grubo honanje:
    - Pritisak korišten pri ovoj operaciji iznosio je 6 jedinica stroja (cca 45 kg);
    - Trajanje operacije 15 minuta;

- Izvršeno je na 4 ruke honing glave, 8 dijamantnih bruseva (dimenzija 125x16x13 mm) prozvođača Chris-Marine, No. 30/137303;

2. Međuobradba honanja:
   - Pritisak korišten pri ovoj operaciji iznosio je 4÷5 jedinica stroja;
   - Trajanje operacije 8 minuta;
   - Izvršeno je na 4 ruke honing glave, 4 brusa prozvođača Chris-Marine No. 20/137304 i 4 brusa No. 20/137305, i to tako da su na svakoj honing ruci bile obje vrste brusa;
3. Završno honanje:
   - Pritisak korišten pri ovoj operaciji iznosio je 4÷5 jedinica stroja, pola vremena, te drugu polovicu vremena s pritiskom 3 jedinice stroja;
   - Trajanje operacije 8 minuta;
   - Izvršeno je na 4 ruke honing glave, 8 bruseva prozvođača Chris-Marine No.20/137316.

Slika 4: Stroj za honanje u radnom prostoru za vrijeme ispitivanja

Slika 5: Stroj za honanje



Točnost geometrijskog oblika i finoća honane površine na izratku ovisi o:

-veličini zrna brusa;
-tvrdoći brusa za honanje;
-vezivu brusnih tijela u brusu za honanje;
-broju operacija honanja (grubo, srednje i fino honanje);
-okomitoj brzini honing stroja;
-brzini okretanja honing glave;
-sredstvu za hlađenje i podmazivanje.

3.2. Ispitna sredstva za hlađenje i podmazivanje

Prilikom ovog ispitivanja najveća se pažnja posvetila različitim sredstvima za hlađenje i podmazivanje, u ovom slučaju, čistih ulja za obradbu metala. Sastav i svojstva ispitnih čistih ulja za obradbu metala, na osnovi mineralnih ulja proizvođača Maziva-Zagreb prikazani su u tablici 1. Ispitna ulja se u sastavu razlikuju po sadržaju baznog ulja i različitih tipova aditiva. To su ulja manje štetna za okoliš i zdravlje ljudi, jer ne sadrže klorparafin, aditiv za poboljšanje svojstava podmazivanja na osnovi klora. Ulja se razlikuju i po fizikalno kemijskim svojstvima. Tako su ulja oznaka POS 29/04, POS 30/04 i POS 31/04 jednake viskozitetne gradacije i to ISO VG 5, prema klasifikaciji ISO 3448, dok ulje oznake POS 32/04 ima znatno nižu viskoznost mjerenu pri 40 ^{0}C. Jedino je ulje POS 30/04 aktivnog tipa, dok su ostala tri neaktivna. Aktivnost se ocjenjuje prema djelovanju na bakrenu pločicu u uvjetima propisanim metodom ispitivanja ISO 2160. Ukoliko se boja pločice ne promijeni, ulje je neaktivno.

Tablica 1: Orijentacijski sastav i svojstva ispitnih ulja za honanje

SASTAV - UZORAK	POS 29/04	POS 30/04	POS 31/04	POS 32/04
PRIRODNO MASNO ULJE, BILJNO	++	++	++	-
ADITIV, FOSFORNI	-	-	+	-
ADITIV, KALCIJEV SULFONAT	++	++	++	+
ADITIV, SULFURIRANO ULJE, AKTIVNO	-	+	-	-
MINERALNO ULJE, NAFTENSKO	+	+	+	-
MINERALNO ULJE, BEZ AROMATA	-	-	-	+
SVOJSTVA /METODA ISPITIVANJA				
Kinem. viskoznost, 40^{0}C, mm^2/s, ISO 3104	5	5	5	1,7
Korozija Cu, 3h, 100^{0}C, ISO 2160	1a	4c	1a	1a
SVOJSTVA PODMAZIVANJA				
-Točka zavarivanja, N, ASTM D 2783	2000	> 8000	3150	1600
-Srednji promjer istrošenja, mm, ASTM D 4172	0,65	0,67	0,43	1,31
-Površina istrošenja, mm^2, Reichertova vaga	15,4	3,2	8,8	24,1
Klasifikacija ulja za obradbu metala	NEAKTIVNO	AKTIVNO	NEAKTIVNO FOSFOR	NEAKTIVNO, NISKO AROMATSKO
Klasifikacija prema ISO 6743/7 [10]	ISO-L-MHE	ISO-L-MHF	ISO-L-MHE	ISO-L-MHB

+ = 1-2 %, ++ = 4-5 %

4. Rezultati ispitivanja

Dobiveni rezultati ispitivanja hrapavosti površine očitani su pomoću uređaja za mjerenje hrapavosti površine Perthometer tip M4P, švedskog proizvođača Mikromess AB. Rezultati su razvrstani prema vrsti ispitnog ulja i fazi obradbe te prikazani u tablicama 2, 3 i 4. Tablica 2 prikazuje rezultate mjerenja hrapavosti površine pri gruboj obradbi, tablica 3 hrapavost površine u međuobradbi te tablica 4 hrapavost nakon završne obradbe površine cilindara.

Tablica 2: Rezultati mjerenja hrapavosti površine cilindara obrađene uz ispitna ulja na grubo (1. grubo honanje)

ULJE	POS 29/04			POS 30/04			POS 31/04			POS 32/04		
Hrapavost, µm	Ra	Rz	Rmax	Ra	Rz	Rmax	Ra	Rz	Rmax	Ra	Rz	Rmax
Mjerenje 1	2,66	16,06	20,32	2,73	15,71	19,36	3,76	21,63	25,92	5,95	35,15	59,20
Mjerenje 2	3,12	16,51	20,48	2,31	16,09	21,60	3,31	19,13	25,44	5,30	29,24	32,64
Mjerenje 3	2,87	16,35	23,04	2,02	13,52	14,96	3,41	21,37	32,00	5,99	34,17	52,80
Mjerenje 4	3,32	15,90	19,36									
Srednja vrijednost	**2,99**	**16,21**	**20,80**	**2,35**	**15,11**	**18,64**	**3,49**	**20,71**	**27,79**	**5,75**	**32,85**	**48,21**

Tablica 3: Rezultati mjerenja hrapavosti površine cilindara obrađene uz ispitna ulja u međufaznom procesu (2. međuobradba honanja)

ULJE	POS 29/04			POS 30/04			POS 31/04			POS 32/04		
Hrapavost, µm	Ra	Rz	Rmax	Ra	Rz	Rmax	Ra	Rz	Rmax	Ra	Rz	Rmax
Mjerenje 1	2,21	12,44	15,20	2,40	13,08	19,68	2,37	13,92	18,24	2,99	17,98	24,16
Mjerenje 2	2,07	11,90	13,36	1,98	12,96	19,52	2,68	16,57	25,28	2,46	14,72	17,44
Mjerenje 3	2,08	12,51	14,08	2,14	13,05	18,08	1,98	10,68	12,08	3,50	23,55	42,56
Mjerenje 4				2,14	12,99	17,44						
Srednja vrijednost	**2,12**	**12,28**	**14,21**	**2,17**	**13,02**	**18,68**	**2,34**	**13,72**	**18,53**	**2,98**	**18,75**	**28,05**

Tablica 4: Rezultati mjerenja hrapavosti površine cilindara obrađene uz ispitna ulja u završnoj fazi (3. završno honanje)

ULJE	POS 29/04			POS 30/04			POS 31/04			POS 32/04		
Hrapavost, µm	Ra	Rz	Rmax	Ra	Rz	Rmax	Ra	Rz	Rmax	Ra	Rz	Rmax
Mjerenje 1	1,84	13,02	22,40	1,41	9,26	11,20	1,88	10,64	12,08	1,50	10,52	16,80
Mjerenje 2	1,51	10,16	11,60	1,49	10,04	14,56	1,99	13,05	25,60	1,97	12,54	18,88
Mjerenje 3	1,52	10,88	16,16	1,32	9,12	13,12	1,65	10,48	14,40	1,77	11,34	13,28
Mjerenje 4	1,64	10,80	12,48				2,13	11,87	14,72			
Srednja vrijednost	**1,63**	**11,22**	**15,66**	**1,41**	**9,47**	**12,96**	**1,91**	**11,51**	**16,70**	**1,75**	**11,47**	**16,32**

Pri analizi rezultata važno je napomenuti da završna hrapavost košuljica koju najčešće zahtijevaju proizvođači dizelovih motora, po parametrima iznosi:

- prosječno odstupanje profila Ra = 1,3 ÷ 1,9 µm;

- prosječna visina neravnina Rz = 8 ÷ 12 μm;
- najveća visina neravnina Rmax = 12 ÷ 18 μm.

Potrebno je napomenuti da svaka faza honanja ima specifičnosti:

1. grubo honanje:

- Zadatak joj je ispravljanje oštećenja radne površine košuljice.
- Korišteni su dijamantni brusevi proizvođača Chris-Marine, No 30/137303, kataloških svojstava:

ostvarena hrapavost Ra = 3,0÷6,0 μm.

2. međuobradba honanja:

- Zadatak joj je uklanjanje oštrih vrhova od grubog honanja na radnoj površini košuljice.
- Korišteni su kameni brusevi proizvođača Chris-Marine, No 20/137304, kataloških svojstava:

veličina zrna: 60;
stupanj tvrdoće: meki;
ostvarena hrapavost Ra = 1,5÷3,0 μm.

- U kombinaciji s kamenim brusevima proizvođača Chris-Marine, No 20/137305, kataloških svojstava:

veličina zrna: 60;
stupanj tvrdoće: srednji;
ostvarena hrapavost Ra = 1,5÷3,0 μm.

3. završno honanje:

- Zadatak joj je ostvarivanje tražene hrapavosti radne površine košuljice.
- Korišteni su kameni brusevi proizvođača Chris-Marine, No 20/137316, kataloških svojstava:

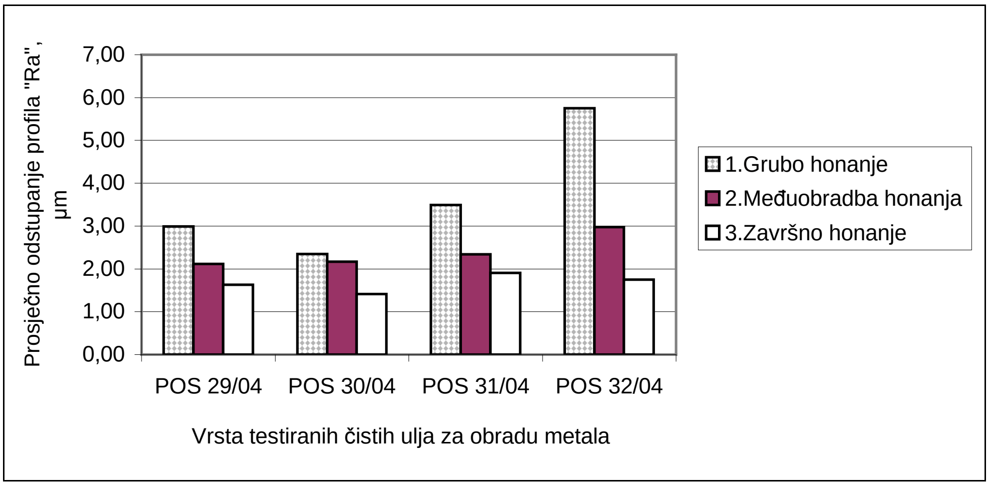
veličina zrna: 100;
stupanj tvrdoće: meki;
ostvarena hrapavost Ra = 0,5÷1,5 μm.

Rezultati dobivenih srednjih vrijednosti mjerenja pojedinih veličina "Ra", "Rz" i "Rmax" prikazani su tablicama 5, 6 i 7 i dijagramima 1, 2 i 3.

Tablica 5: Prosječno odstupanje profila "Ra" (μm) srednjih vrijednosti mjerenja

"Ra", μm	OBRADBA		
ISPITNO ULJE	1. grubo honanje	2. međuobradba honanja	3. završno honanje
POS 29/04	2,99	2,12	1,63
POS 30/04	2,35	2,17	1,41
POS 31/04	3,49	2,34	1,91
POS 32/04	5,75	2,98	1,75

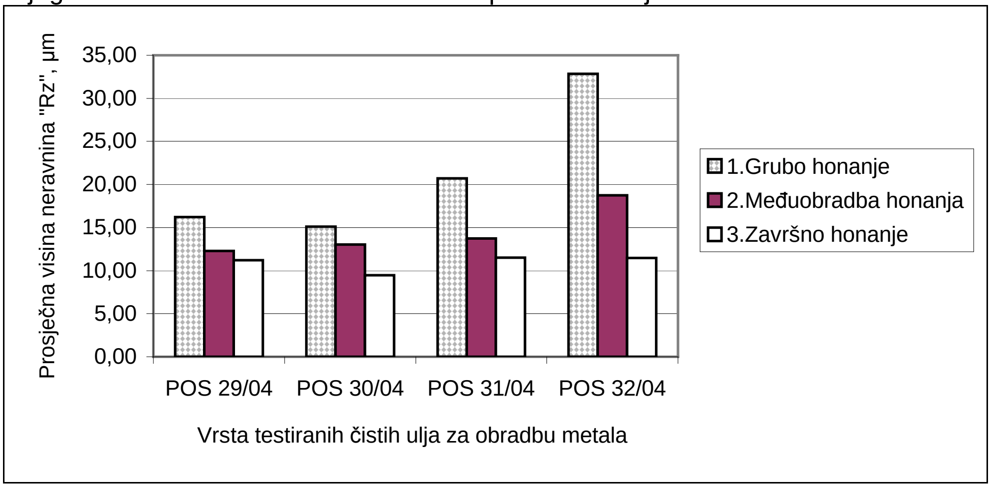
Dijagram 1: Prikaz dobivenih rezultata usporedbom vrijednosti "Ra"



Tablica 6: Prosječna visina neravnina "Rz" (µm) srednjih vrijednosti mjerenja

"Rz", µm	OBRADBA		
ISPITNO ULJE	1. grubo honanje	2. međuobradba honanja	3. završno honanje
POS 29/04	16,21	12,28	11,22
POS 30/04	15,11	13,02	9,47
POS 31/04	20,71	13,72	11,51
POS 32/04	32,85	18,75	11,47

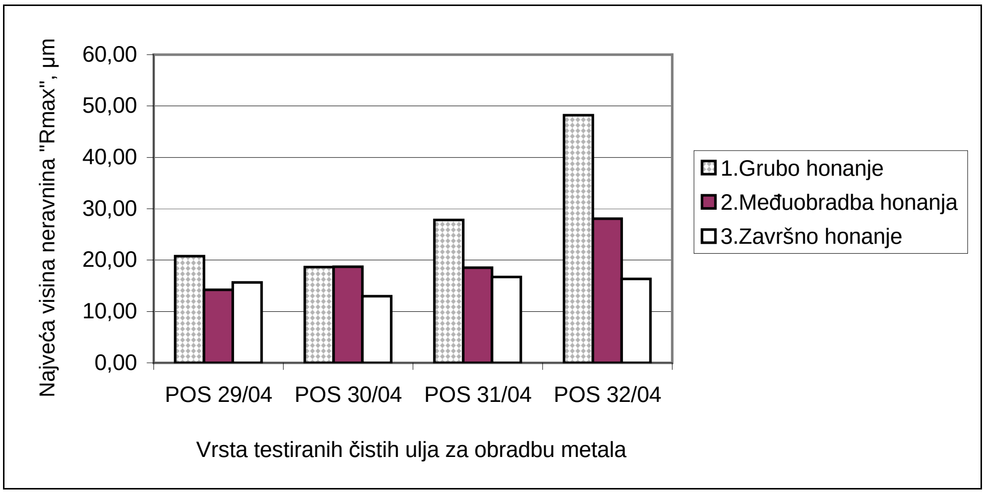
Dijagram 2: Prikaz dobivenih rezultata usporedbom vrijednosti "Rz"



Tablica 7: Najveća visina neravnina "Rmax" (μm) srednjih vrijednosti mjerenja

"Rmax", μm	OBRADBA		
ISPITNO ULJE	1. grubo honanje	2. međuobradba honanja	3. završno honanje
POS 29/04	20,80	14,21	15,66
POS 30/04	18,64	18,68	12,96
POS 31/04	27,79	18,53	16,70
POS 32/04	48,21	28,05	16,32

Dijagram 3: Prikaz dobivenih rezultata usporedbom vrijednosti "Rmax"



5. Analiza dobivenih rezultata istraživanja

1. Honanjem čistim uljem za obradbu metala POS 32/04:
   - Dobivena je najveća hrapavost i prilikom 1. faze grubog honanja i prilikom 2. faze međuobradbe, a prilikom 3. faze, završnim honanjem, ostvarena je zadovoljavajuća hrapavost za radnu površinu košuljica cilindara.
   - Najpogodnije sredstvo od svih ispitanih, jer najbolje odvodi, ispire košuljicu te nema lijepljenja nikakvih ostataka metalne prašine nastale honanjem te iščupanih zrnaca s honing bruseva na površini obrađene košuljice ili na samim brusevima.
   - Najpogodniji za obradbu jako oštećenih košuljica, jer pri svakoj fazi ostvaruje gornju granicu hrapavosti, koju proizvođač bruseva kataloški iznosi, što omogućuje lakši proces honanja, tj. visoki koeficijent brušenja.

2. Honanjem čistim uljem za obradbu metala POS 31/04:
   - Dobivena je manja hrapavost i prilikom 1. i 2. faze i to za oko 50 % manje, u odnosu na POS 32/04, a prilikom 3. faze dobivena hrapavost je bila i nešto veća.

- Ispiranjem prilikom 1. faze nije dolazilo do lijepljenja na površini obrađene košuljice, ali je dolazilo do lijepljenja na samim brusevima.
- Ispiranjem prilikom 2. faze nije dolazilo do lijepljenja na samim brusevima, ali je uočeno na površini obrađene košuljice.
- Ispiranjem prilikom 3. faze dolazilo je do slabog lijepljenja na površini obrađene košuljice i na samim brusevima.
- Zadovoljavajuće i što se tiče tražene hrapavosti i što se tiče ispiranja prilikom honanja.

3. Honanjem čistim uljem za obradbu metala POS 29/04:
   - Dobivena hrapavost i prilikom 1. i 2. faze na doljnjoj granici hrapavosti koju proizvođač bruseva kataloški iznosi te time ne omogućuje tako dobro grubu fazu honanja.
   - Prilikom 3. faze dobivena hrapavost je bila identična onoj dobivenoj uljem POS 32/04, dakle zadovoljavajuća.
   - Ispiranje prilikom svih faza honanja je bilo zadovoljavajuće te nismo nailazili niti u jednoj fazi honanja na ostatke metalne prašine te iščupanih zrnaca bruseva na površini obrađene košuljice i na samim brusevima.

4. Honanjem čistim uljem za obradbu metala POS 30/04:
   - Dobivene hrapavosti prilikom 1. i 2. faze su bile gotovo jednake.
   - Vrijednost hrapavosti 1. faze, Ra=2,35 μm, bila je ispod one koju proizvođač bruseva kataloški iznosi, Ra > 3 μm, te time ne omogućuje grubu fazu honanja.
   - Dobivena hrapavost prilikom 3. faze je bila najfinija od svih ispitanih ulja, te je preporučljivo da se ovo ispitano ulje koristi za «visoko poliranje».
   - Ispiranje prilikom 1. i 3. faze honanja je bilo zadovoljavajuće, dok smo prilikom 2. faze naišli na manje ostatke metalne prašine te iščupanih zrnaca bruseva na površini obrađene košuljice i na samim brusevima.

6. Zaključak ispitivanja

Analizirana je mogućnost primjene pojedinih čistih ulja za honanje košuljica cilindara motora. Postupak honanja u ovom slučaju primjenjuje se za pripremu radne površine košuljice cilindra za bolje prianjanje ulja u radu motora.

Da bi se ostvarilo zadovoljavajuće prianjanje ulja na radnoj površini košuljice cilindra, obvezatno je površinu obraditi u sve tri faze honanja: grubo, međuobradba i završno honanje.

Istraživanjem je utvrđeno da se najbolji rezultat honanja ostvaruje uljem POS 32/04, kojim su se zadovoljili svi zahtjevi proizvođača uređaja za honanje te proizvođača košuljica cilindara motora.

THE POSSIBILITY OF APPLYING NEAT METALWORKING OILS FOR CYLINDER LINER HONING

Abstract

Honing is a procedure treating the finest metal surfaces in order to achieve the required precision and quality of treated surfaces. Honing itself, as well as proceses of grating, milling, grinding, i.e. using cutting for the shaping of metal materials, is in its activity limited to a relatively thin surface layer of the workpiece, mostly causing cold plastic deformation, without any long-term impacts on either the structure or properties of the material.

When performing the process of honing, it is extremely important that the working surface be washed by considerable volumes of the cooling and lubrication agents. The working surface needs to be cooled, so as not to cause any structural change due to the processes of recrystallization and release. Apart from that, rinsing takes away the metal dust generated by honing, as well as the pulled out grinding wheel grains. Research in this area is today oriented towards applying new cooling and lubricating agents.

Based on economic and environmental analysis, as well as that of the quality of honing procedure when applying cooling and lubricating agents based on mineral oils, containing various types of additives, the paper also considers the possibility of applying new oils for the honing of cylinder bores.

1. Introduction

Cylinder bores must - given their behaviour during operation and their service life – meet rather severe requirements. Using precision turning lathes and cutting tools, through techniques of rough honing, final working and honing, precision surface of cylinder bores is achieved, characterized by fine tolerance.

Honing is a procedure of machining the finest cylinder bore surfaces in order to achieve required presision and quality of surfaces – in our case the operating surface of cylinder bore [1].

Honing itself, as well as processes of turning, milling, grinding, i.e. using cutting for the shaping of metal materials, is in its activity limited to a relatively thin surface layer of the workpiece, mostly causing cold plastic deformation, but it needs to be stressed that it has no long-term impact on the material structure, and hence also its properties [2].

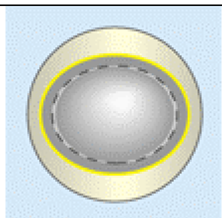
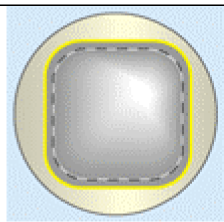
The internationally acknowledged Swedish company Chris-Marine is - relying on its own experience of over 40 years, as well as closely co-operating with the leading engine manufacturers, designing special high quality equipment for the maintenance of diesel plants, including the making of honing machines. Using such machinery for special treatment results in improved performances of diesel engines, reduced cylinder bore operating surface wear, thus achieving major savings in operational costs.

2. Reasons for honing

The first aim of honing is the extension of the service life of cylinders and piston rings. Engine service often results in increased wear of the cylinder surface, as well as damaged and broken piston rings. Today, engines are capable of operating with the average temperature of the bore liner surface of 250 ^{0}C, pressure of up to 190 bar, and, as a result, piston rings are subjected to higher loads, which may soon result in excessive cylinder bore wear [3].

Due to all this, imperfections of the cylinder liner surface, caused by the environment i.e. by wear (Figure 2a), may be both corrected and prevented by honing. With a unique spring strain, the honing head of the Chris-Marine honing machine improves the dimensions of bores by forming a circular form out of an out-of-roundness one (Figure 1) or from otherwise worn out bores. At the same time, the machine also drills the surface of the cylinder bores in order to achieve a proper roughness and a crosshatched operating surface (Figure 2b).

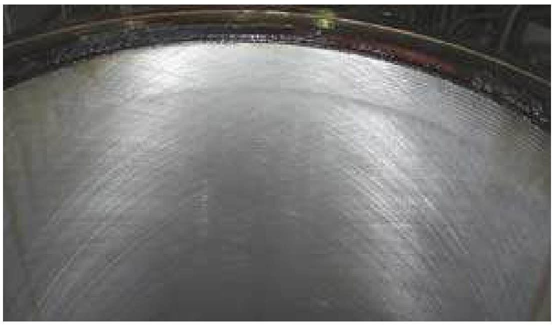
Figure 1: Presentation of two types of machine heads for achieving cylindrical shape

4 arms type S, for standard treatment, out-of-roundness wear		8 arms type S2, for several various wears and non-cylindric shapes	
			

Another reason for honing is the reduction of the risk consisting in compression leakage, wear, and jamming. The main problem of out-of-roundness form and wear in the upper part of bores due to service may be corrected through honing. Honing also creates a crosshatched operating surface, which is consistent with engine manufacturer recommendations. Such a crosshatched operating surface serves for easier maintenance of a thin oil film between cylinder bore and piston rings, thus considerably improving reduced wear of piston rings, as well as reduced lubricating oil consumption.

Figure 2a: Surface of cylinder bore before honing

Figure 2b: Surface of cylinder bore after honing

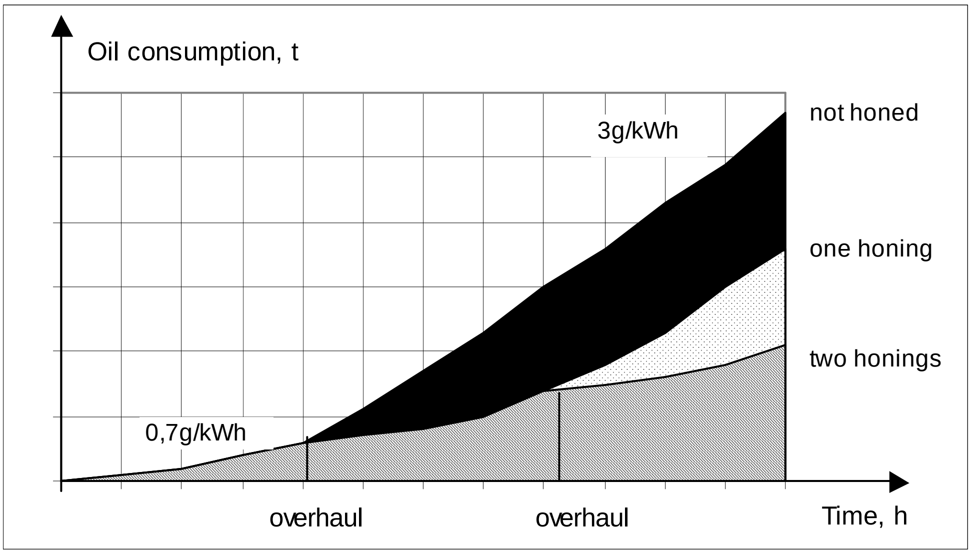


The third reason for honing is a reduced consumption of the lubricating oil. Figure 3 shows oil consumption for the lubrication of honed and unhoned cylinder bore, 4-stroke diesel engine with the output power of 10 000 kW [4]. It may be seen that oil consumption is considerably lower if the bore surface is treated by honing during regular engine service (overhaul).

An example of a schematic presentation of oil consumption:
- Regularly honed cylinder: 0.7 g/kWh x 10,000 kW x 6,000 h = 42 t/y
- Non-honed cylinder: 3 g/kWh x 10,000 kW x 6,000 h = 180 t/y.

Remaining combustion in the cylinder impacts the deposits on the piston crown, and, during piston operation, while it moves from the upper to the lower standstill, it may cause vertical cuts, channels, on cylinder bores. Honing over the said channels and other rough spots achieves normalized consumption of lubricating oil. That is why piston rings must never be replaced in the piston, without first honing cylinder bores.

Figure 3: Presentation of oil consumption with unhoned and regularly honed engine bore



3. Testing Process

3.1. Honing machine

The test was performed in the operating room of the Ivis Marine company, a part of the Viktor Lenac shipyard in Rijeka (Figure 4). Honing the cylinder bore of the engine Sulzer Z 40/48 was performed by a honing machine manufactured by Chris-Marine, Sweden, type LB2 [5] and honing head of the machine S2 31/49 (Figure 5) .

Grinding wheels in the honing head are radially adjustable through gear transmission, so that – within rather narrow limits – they may change mensurations, improve geometrical form (out-of-roundness to cylindric), and make the treated bore surface finer.

The process of honing while testing each of the cooling and lubrication agents has been divided into three parts [6,7,8,9].

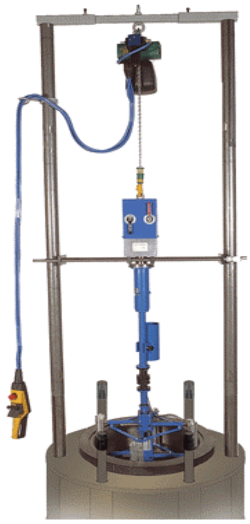
1. Rough honing:
    - Pressure used in this operation was 6 machine units (ca. 45 kg);
    - Duration of operation: 15 minutes;

- Performed on 4 arms of the honing head, 8 diamond chisels (dimension: 125x16x13 mm), manufactured by Chris-Marine, No. 30/137303;

2. Inter mediate honing:
    - Pressure used in this operation was 4÷5 machine units;
    - Duration of operation: 8 minutes;
    - Performed on 4 arms of the honing head, 4 grinding wheels manufactured by Chris-Marine No. 20/137304 and 4 grinding wheels No. 20/137305, with each honing arm having both kinds of grinding wheels;
3. Final honing:
    - Pressure used in this operation was 4÷5 machine units half the time, and the other half 3 machine units;
    - Duration of operation: 8 minutes;
    - Performed on 4 arms of the honing head, 8 grinding wheels manufactured by Chris-Marine No.20/137316.

Figure 4: Honing machine in workspace during testing

Figure 5: Honing machine



The accuracy of geometrical form and the delicacy of the honed surface on the workpiece depends on:

-grinding wheel grain size;
-firmness of the honing grinding wheel;
-binder of grinding bodies in the grinding wheel;
-number of honing operations (rough, medium and fine honing);
-vertical velocity of the honing machine;

-rotation velocity of the honing head;
-cooling and lubrication agent.

3.2. Test agents for cooling and lubrication

During the test, most attention was paid to various cooling and lubrication agents, in this case, neat metalworking oils. The composition and properties of tested neat metalworking oils, based on mineral oils produced by Maziva-Zagreb, are shown in Table 1. Test oils differ in their composition in terms of base oil content and different additive types. They are less environmentally harmful or human health hazardous oils, since they do not contain chlorinated paraffin - additive for improving lubrication properties (chlorine-based). Oils differ also according to their physico-chemical properties. Thus, oils labelled POS 29/04, POS 30/04 and POS 31/04 have equal viscosity gradations: ISO VG 5, according to classification ISO 3448, whereas oil labelled POS 32/04 has much lower viscosity measured at 40 ^{0}C. Only the oil POS 30/04 is active, while the remaining three are inactive. Activity is evaluated according to the effect on copper plate under conditions prescribed by the test method ISO 2160. Unless the color of the plate changes, the oil is inactive.

Table 1: Orientation composition and properties of test honing oils

COMPOSITION - SAMPLE	POS 29/04	POS 30/04	POS 31/04	POS 32/04
NATURAL FAT OIL, VEGETABLE	++	++	++	-
ADDITIVE, PHOSPHOROUS	-	-	+	-
ADDITIVE, CALCIUM SULPHONATE	++	++	++	+
ADDITIVE, SULPHURIZED OIL, ACTIVE	-	+	-	-
MINERAL OIL, NAPHTHENIC	+	+	+	-
MINERAL OIL, NO AROMATICS	-	-	-	+
PROPERTIES /TEST METHOD				
Kinem. viscosity, 40^{0}C, mm^2/s, ISO 3104	5	5	5	1,7
Corrosion Cu, 3h, 100^{0}C, ISO 2160	1a	4c	1a	1a
LUBRICATION PROPERTIES				
-Welding point, N, ASTM D 2783	2000	> 8000	3150	1600
-Mean wear diameter, mm, ASTM D 4172	0,65	0,67	0,43	1,31
-Wear surface, mm^2, Reichert's scales	15,4	3,2	8,8	24,1
Classification of metalworking oils	INACTIVE	ACTIVE	INACTIVE PHOSPHORO US	INACTIVE, LOW AROMATIC
Classification according to ISO 6743/7 [10]	ISO-L-MHE	ISO-L-MHF	ISO-L-MHE	ISO-L-MHB

+ = 1-2 %, ++ = 4-5 %

4. Test results

The obtained test results, surface roughness, was read off using the device for measuring surface roughness Perthometer tip M4P, by Swedish manufacturer Mikromess AB. The results were classified according to test oil type and treatment phase, and shown in Tables 2, 3 and 4. Table 2 shows results of measuring surface roughness at rough treatment; Table 3 in inter mediate treatment, and Table 4 after the final treatment of cylinder surface.

Table 2: Results of measuring cylinder surface roughness treated using test oils in rough phase (1 Rough honing)

OIL	POS 29/04			POS 30/04			POS 31/04			POS 32/04		
Roughness, µm	Ra	Rz	Rmax	Ra	Rz	Rmax	Ra	Rz	Rmax	Ra	Rz	Rmax
Measurement 1	2,66	16,06	20,32	2,73	15,71	19,36	3,76	21,63	25,92	5,95	35,15	59,20
Measurement 2	3,12	16,51	20,48	2,31	16,09	21,60	3,31	19,13	25,44	5,30	29,24	32,64
Measurement 3	2,87	16,35	23,04	2,02	13,52	14,96	3,41	21,37	32,00	5,99	34,17	52,80
Measurement 4	3,32	15,90	19,36									
Mean value	**2,99**	**16,21**	**20,80**	**2,35**	**15,11**	**18,64**	**3,49**	**20,71**	**27,79**	**5,75**	**32,85**	**48,21**

Table 3: Results of measuring cylinder surface roughness treated using test oils in inter-phase process (2. Inter mediate honing)

OIL	POS 29/04			POS 30/04			POS 31/04			POS 32/04		
Roughness, µm	Ra	Rz	Rmax	Ra	Rz	Rmax	Ra	Rz	Rmax	Ra	Rz	Rmax
Measurement 1	2,21	12,44	15,20	2,40	13,08	19,68	2,37	13,92	18,24	2,99	17,98	24,16
Measurement 2	2,07	11,90	13,36	1,98	12,96	19,52	2,68	16,57	25,28	2,46	14,72	17,44
Measurement 3	2,08	12,51	14,08	2,14	13,05	18,08	1,98	10,68	12,08	3,50	23,55	42,56
Measurement 4				2,14	12,99	17,44						
Mean value	**2,12**	**12,28**	**14,21**	**2,17**	**13,02**	**18,68**	**2,34**	**13,72**	**18,53**	**2,98**	**18,75**	**28,05**

Table 4: Results of measuring cylinder surface roughness treated using test oils in final phase (3. Final honing)

OIL	POS 29/04			POS 30/04			POS 31/04			POS 32/04		
Roughness, µm	Ra	Rz	Rmax	Ra	Rz	Rmax	Ra	Rz	Rmax	Ra	Rz	Rmax
Measurement 1	1,84	13,02	22,40	1,41	9,26	11,20	1,88	10,64	12,08	1,50	10,52	16,80
Measurement 2	1,51	10,16	11,60	1,49	10,04	14,56	1,99	13,05	25,60	1,97	12,54	18,88
Measurement 3	1,52	10,88	16,16	1,32	9,12	13,12	1,65	10,48	14,40	1,77	11,34	13,28
Measurement 4	1,64	10,80	12,48				2,13	11,87	14,72			
Mean value	**1,63**	**11,22**	**15,66**	**1,41**	**9,47**	**12,96**	**1,91**	**11,51**	**16,70**	**1,75**	**11,47**	**16,32**

As regards the analysis of results, it is important to point out that the most required final bore roughness by diesel engine manufacturers, as per parameters:

- average roughness Ra = 1,3 ÷ 1,9 μm;
- average peak-to-valleyheight of asperities Rz = 8 ÷ 12 μm;
- maximum peak-to-valleyheight of asperities Rmax = 12 ÷ 18 μm.

It is necessary to mention that each honing phase has its specific properties:

1. Rough honing:
   - Its task is to correct damages of the bore operating surface.
   - Used were diamond grinding wheels manufactured by Chris-Marine, No 30/137303, with the following catalogue properties:
     achieved roughness Ra = 3,0÷6,0 μm.

2. Inter mediate honing:
   - Its task is to remove sharp tops of rough honing on the bore surface.
   - Used were stone grinding wheels manufactured by Chris-Marine, No 20/137304, with the following catalogue properties:
     grain size: 60;
     hardness degree: soft;
     achieved roughness Ra = 1,5÷3,0 μm.
   - Combined with stone grinding wheels manufactured by Chris-Marine, No 20/137305, with the following catalogue properties:
     grain size: 60;
     firmness degree: medium;
     achieved roughness Ra = 1,5÷3,0 μm.

3. Final honing:
   - Its task is to achieve desired roughness of the bore operating surface.
   - Used were stone grinding wheels manufactured by Chris-Marine, No 20/137316, with the following catalogue properties:
     grain size: 100;
     hardness degree: soft;
     achieved roughness Ra = 0,5÷1,5 μm.

The results of obtained medium individual measurement values of "Ra", "Rz" i "Rmax" are shown in Tables 5, 6 i 7 and diagrams 1, 2 and 3.

Table 5: Average aberration of profile "Ra" (μm) of mean measuring values

"Ra", μm	TREATMENT		
TEST OIL	1. Rough honing	2. Inter mediate honing	3. Final honing
POS 29/04	2,99	2,12	1,63
POS 30/04	2,35	2,17	1,41
POS 31/04	3,49	2,34	1,91
POS 32/04	5,75	2,98	1,75

Diagram 1: Presentation of obtained results comparing values "Ra"

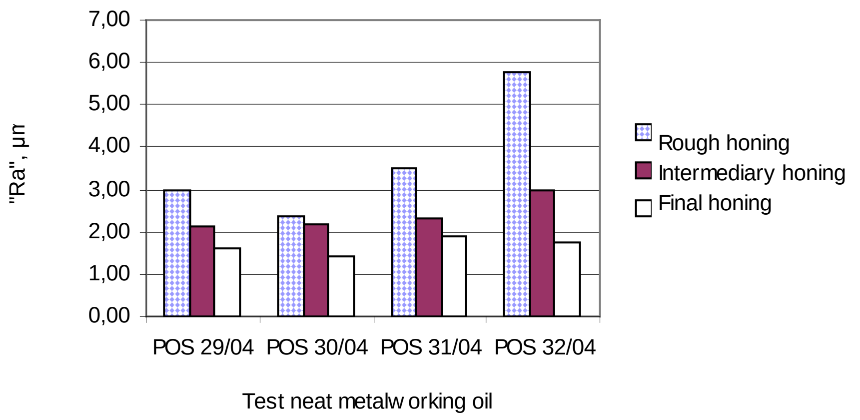


Table 6: Average height of uneven spots "Rz" (µm) of mean measuring values

"Rz", µm	TREATMENT		
TEST OIL	1. Rough honing	2. Inter mediate honing	3. Final honing
POS 29/04	16,21	12,28	11,22
POS 30/04	15,11	13,02	9,47
POS 31/04	20,71	13,72	11,51
POS 32/04	32,85	18,75	11,47

Diagram 2: Presentation of obtained results comparing values "Rz"

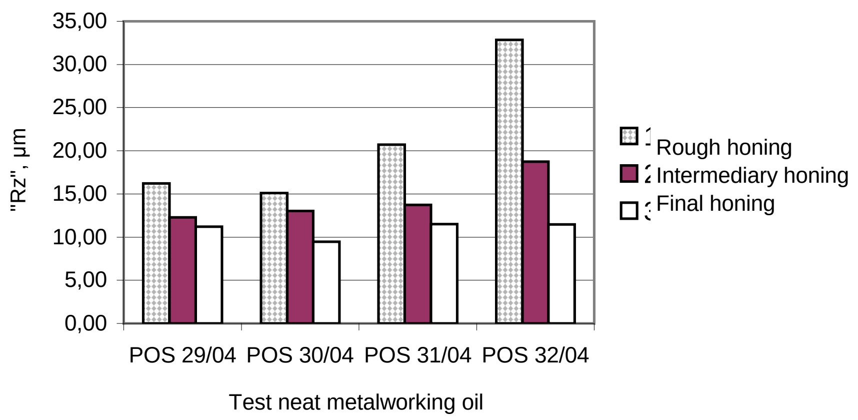
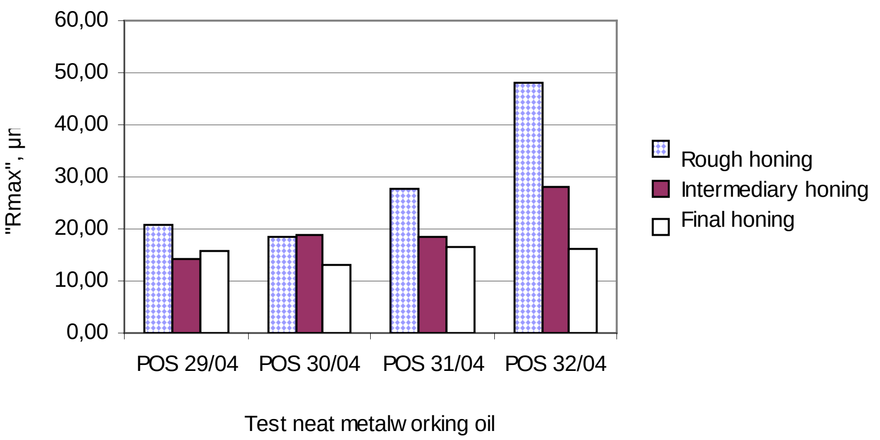


Table 7: Greatest height of roughness spots "Rmax" (μm) of mean measuring values

"Rmax", μm	TREATMENT		
TEST OIL	1. Rough honing	2. Inter mediate honing	3. Final honing
POS 29/04	20,80	14,21	15,66
POS 30/04	18,64	18,68	12,96
POS 31/04	27,79	18,53	16,70
POS 32/04	48,21	28,05	16,32

Diagram 3: Presentation of obtained results comparing values "Rmax"



5. Analysis of the obtained research results

1. Honing by neat metalworking oil POS 32/04:
   - The obtained roughness in phase 1 of rough honing and phase 2 of inter mediate treatment was the highest, while, during phase 3, the final honing, a satisfactory roughness was obtained for the operating surface of cylinder bores;
   - The most suitable agent of all, since it conducts the best, rinses the bore, and there is no sticking of any metal dust remains created by honing or plugged out grains from the honing grinding wheels on the surface of treated bore or on the grinding wheels themselves;
   - Most suitable for the treatment of heavily damaged bores because in every phase it achieves the upper roughness value, mentioned by grinding wheel manufacturer in the catalogue, thus facilitating the honing process, i.e. achieving high grinding coefficient.
2. Honing by neat metalworking oil POS 31/04:

- The obtained roughness in phases 1 and 2 was by about 50 % less with regard to POS 32/04, while, during phase 3, the obtained roughness was even somewhat higher;
- Rinsing during phase 1 did not cause any sticking to the surface of treated bore, but there was sticking on the grinding wheels themselves;
- Rinsing during phase 2 did not cause any sticking to the grinding wheels themselves, but it was spotted on the surface of treated bore;
- Rinsing during phase 3 caused low sticking on both the surface of treated bore and the grinding wheels themselves;
- Satisfactory in terms of both required roughness and rinsing while honing.

3. Honing by neat metalworking oil POS 29/04:
   - The obtained roughnesses in phases 1 and 2 were on the bottom roughness limit that the grinding wheel manufacturer mentions in the catalogue, hence not enabling such a good rough honing phase;
   - During phase 3, the obtained roughness was identical to the one obtained using oil POS 32/04, i.e. satisfactory;
   - Rinsing during all phases of honing was satisfactory and there were no remaining metal dust particles or pulled out grains in any honing phase either on the treated bore surface or on the grinding wheels themselves.

4. Honing by neat metalworking oil POS 30/04:
   - The obtained roughnesses in phases 1 and 2 were nearly equal;
   - Roughness value of phase 1, Ra=2,35 μm, was below the one that grinding wheel manufacturer mentions in the catalogue, Ra > 3 μm, hence not enabling rough honing phase;
   - The obtained roughness in phase 3 was the finest among all tested oils, and it is recommendable that this particular test oil be used for «high polishing»;
   - Rinsing during phases 1 and 3 of honing was satisfactory, whereas, during phase 2, there were some minor remnants of metal dust and pulled out grinding wheel grains on the surface of treated bore, as well as on grinding wheels themselves.

6. Conclusion

We have analyzed the possibility of applying individual neat oils for honing engine cylinder bores. The honing procedure is in this case applied for preparing the operating surface of the cylinder bore for better adhesion of oil in service.

In order to achieve satisfactory oil adhesion to the operating surface of the cylinder bore, one must work the surface in all three phases of honing: rough, inter mediate and final honing.

The research has shown that the best honing results are achieved using oil POS 32/04, meeting all the requirements of both the honing devices and the engine cylinder bores manufacturers.

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621.924.5	brušenje i honanje površine cilindara	cilinder liner grinding and honing
621.43-222.2	košuljica cilindra	cylinder liner
621.892.6	ulje za obradbu metala	metal-working oil

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