

INVESTIGATION OF CAUSES OF SCRAP OCCURRENCE IN THREAD CUTTING ON STEEL SLEEVES FOR MOTORCAR INDUSTRY

Received - Primljeno: 2006-03-08
Accepted - Prihvaćeno: 2006-09-25
Professional Paper - Strukovni rad

This paper studies causes of scrap occurrence, wear and breakage of cutters during thread cutting of steel sleeves poured in Al die castings of motor car engine components. It was concluded that the reason for occurrence of problems with thread cutting of sleeves most probably should be attributed to the fact whether hardness value reaches 200 HB or over 250 HB. The most probable reason for over wear and consequently to breakage of cutters and scrap occurrence, although castings display top quality, lies in the fact that the internal diameter of sleeves frequently falls down under minimally allowed tolerances for threaded sleeves.

Key words: *Al die casting, carriers, cutting of threads, sleeves, scrap*

Istraživanje uzroka nastajanju škarta pri urezivanju navoja u čelične umetke tlačno lijevanih Al nosača dijelova motora. U radu je istraživao uzrok nastajanju škarta, trošenja i lomljenja ureznika pri urezivanju navoja u čelične umetke "čahure" koji su zaliveni u aluminijskim tlačnim odljevcima nosača dijelova motora automobila. Zaključeno je da se razlog problemu s urezivanjem navoja u čahure najvjerojatnije ne nalazi u tome da li je njihova tvrdoća ispod 200HB ili je preko 250HB. Vjerojatni razlog prekomjernom trošenju pa i lomu ureznika te nastajanju škarta, i pored toga što su nosači kvalitetno odliveni, je taj što se unutarnji promjer čahura često nalazi ispod minimalno propisanog za urezivani navoj.

Ključne riječi: *Al tlačni ljev, nosači, urezivanje navoja, čahure, škart*

INTRODUCTION

Nonconforming, and for their purpose unusable castings, not fulfilling the requirements of the standard and/or with customer agreed delivery conditions represent scrap [1, 2]. Scrap is manifested in foundries as waste in material, energy and labor. Its efficient monitoring and supervision is possible only when the quality criteria have been unequivocally established, not only for the final product but also for single operations. Taking into account harsh market competition, only top quality product can be sold, and that at prices acceptable to customer. Scrap can significantly influence the profitability of production. Therefore, it is of the utmost importance, that causes of scrap occurrence are discovered as soon as possible. The biggest waste is when scrap occurs in final stage of casting production.

Steel sleeves for carriers of motor components in car industry have been taken as an example of unforeseen increase in production cost. During the process of die casting of aluminum carriers, steel sleeves have been cast into them, and additionally threads have been cut. It was

observed that cutters not only showed an unexpected wear but they frequently broke during threading. Consequently, there was increase in costs and price of the casting, and top quality castings turned frequently into scrap.

EXPERIMENTAL WORK

For the purpose of research of causes of scrap occurrence 5 castings have been taken by random sampling prior to thread cutting, and 5 raw steel sleeves in *as delivered condition*. These castings were used for testing of chemical composition, microstructure, hardness values and dimensional control to establish causes of waste occurrence during sleeve thread cutting.

PROPERTIES OF DIE CASTED Al CARRIERS

Motor carriers are manufactured by the process of die casting of Al alloy AlSi9Cu3(Fe)L226 obtained from secondary aluminum. Thereby, the melt at the temperature of 720 °C is poured around two steel sleeves, cooled with oil emulsion to ~ 300 °C, and afterwards cooled at air temperature. The entire process is automated. The appearance of the carrier is shown in Figure 1.

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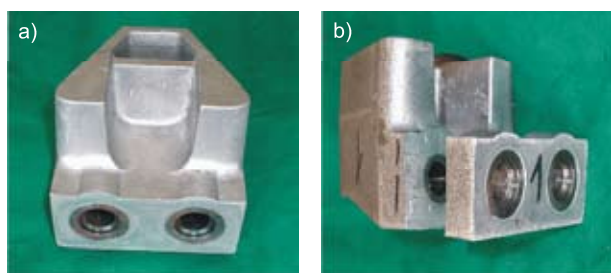


Figure 1. Carrier of motor components: a) Die cast; b) cut for experimental needs
Slika 1. Nosač dijelova motora: a) odliven tlačnim lijevanjem; b) prerezan za potrebe ispitivanja

Although foundries carry out regular control of chemical composition, an independent laboratory analyzed samples of one of the five motor carriers.

Test results are shown in Table 1., where it can be observed that chemical composition corresponds approximately to that declared for the alloy AlSi9Cu3(Fe)L-226 [3].

Table 1. Tested chemical composition of Al alloy (contained elements)
Tablica 1. Ispitani kemijski sastav Al legure (udjel elemenata)

Contained elements					
Si	Fe	Cu	Mn	Mg	Zn
9,43	1,18	2,82	0,193	0,195	0,564
Ni	Cr	Pb	Sn	Ti	Al
0,037	0,024	0,212	0,038	0,030	85,29

Figure 2. shows the characteristic cross section microstructure of Al casting. It should be noticed that the microstructure corresponds to the customer contract provisions, whereby smaller irregularities in the form of internal gas holes and small inclusions of impurities [4] can also be observed.

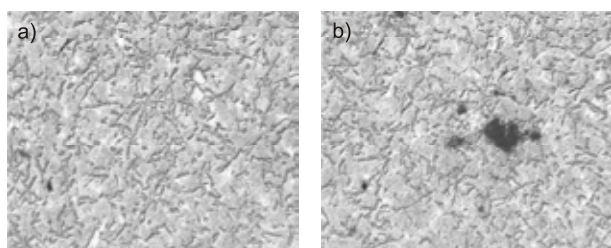


Figure 2. Typical cross section microstructure of Al carriers; Magnification 220x, Etching: Nital + hydrogen fluor acid (HF)
Slika 2. Karakteristična struktura poprečnog presjeka Al nosača. Povećanje 220 puta. Nagrizanje: nital + fluorovodonična kiselina (HF)

Two probe specimens for static tensile testing and hardness control were prepared from Al carriers. The results are shown in Table 2.

It can be observed that the mechanical properties of die cast Al carriers lie within the boundaries set for AlSi9Cu3(Fe)L-226 [3].

Table 2. Mechanical properties and hardness values of die cast Al carriers

Tablica 2. Mehanička svojstva i tvrdoća tlačno lijevanih Al nosača

Carrier	Properties			
	R_m / MPa	R_c / MPa	As / %	HB 10/500/15
I.	212	168	1,8	83
II.	243	176	1,5	76

The declared material of sleeves is the steel C45 (according to EN 10083-1) [5]. From results obtained by chemical analyses (Table 3.) it can be observed that composition of sleeves corresponds to the standard requirements.

Table 3. Characteristic chemical composition of steel sleeves, base material C45

Tablica 3. Karakteristični kemijski sastav čeličnih čahura; osnovni materijal C45

Chemical composition				
	C	Si	Mn	S
Sleeve	0,48	0,28	0,75	0,022
EN 10083-1	0,42 0,50	max 0,40	0,50 0,80	max 0,035
	P	Cr	Ni	Mo
Sleeve	0,008	0,13	0,04	0,01
EN 10083-1	max 0,035	max 0,40	max 0,40	max 0,10

According to [5] as delivered annealed steel (C45E+A) must have hardness value of maximum 207 HB, and in normalized condition (C45E+S) this value reaches max. 255 HB.

Hardness value control HB 2/120/15 ($F/D^2 = 30$) was carried out on poured steel sleeves, at the front side, and on the cut casting (sample for metallographic examination).

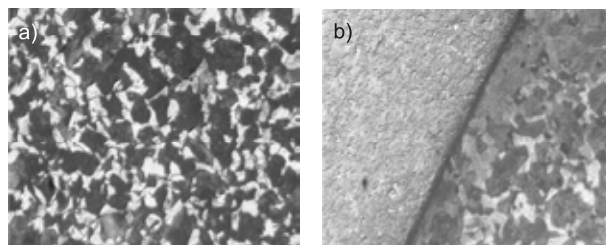


Figure 3. Characteristic microstructure of cross section of steel sleeves; Magnification 220x, Nital etching: a) sleeve center; b) sleeve margin (up to Al.)

Slika 3. Karakteristična mikrostruktura poprečnog presjeka čeličnih čahura. Povećanje 220 puta. Nagrizanje nital: a) sredina čahure; b) rub čahure (do Al.)

The measured hardness values range from 250 to 270 HB. It was not observed that point of measurement affected the measured values.

Metallographic examination on the cross section of steel sleeves (Figure 3.a) was carried out. The microstructure is rather homogenous ferrite - pearlite structure, typical for a normalized steel and no significant differences between the central and marginally located areas of Al (Figure 3.b) could be observed.

The control of cylindrical bores has been carried out on all 5 carriers, parallelism of axes, perpendicularity of symmetry lines (on the surface of Al casting) and span between

symmetry lines of the sleeves. The control was performed on 3D device MERLIN 1100 TWIN STAR (Frerranti International), and results are shown in Table 4. The diameter of the sleeve bore (and cylindricity) have been controlled at two points: $1 = d_1$, at depth of 8 mm, $2 = d_2$ on 25 mm depth. Typical properties of the casting, those which define correctness of the carrier for installation into motor vehicle, are shown in Figure 4.

The results given in Table 4. indicate that parallelism, perpendicularity and symmetry line axes span of the sleeves lie within the frame specified in the technical documentation.

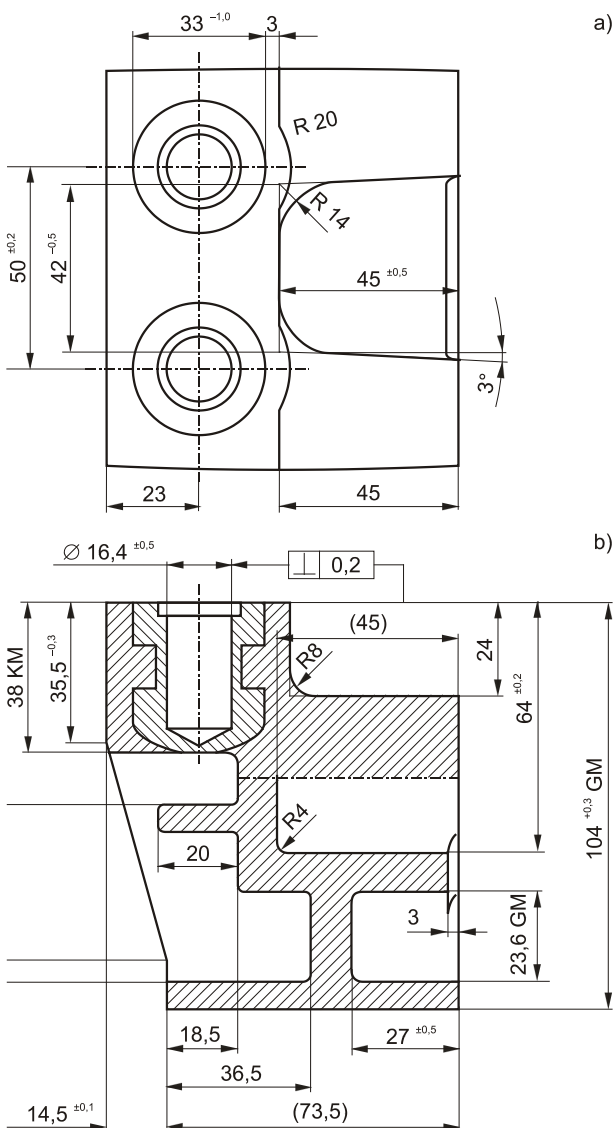


Figure 4. Typical dimensions of Al casting: a) span of symmetry lines of sleeve bores; b) diameter, depth and perpendicularity to sleeve symmetry lines

Slika 4. Karakteristične dimenzije Al odljevaka: a) razmak simetrala rupa steznih čahura; b) promjer, dubina i okomitost čela na simetralu steznih čahura

Table 4. Results of 3D control of sleeves in Al carrier
 Tablica 4. Rezultati 3D kontrole čahura u Al nosaču

Carrier No.	Sleeves	Cylindricity /0/ mm	Parallelism of symmetry lines // mm	Perpend. of sim. lines of front of casting ⊥ / mm	Symmetry line span / mm	The smallest diameter φ / mm
1	I	0,010	0,0384	0,0527	50,1621	16,4147
	II	0,0006		0,0354		16,4927
2	I	0,036	0,0214	0,0145	49,9116	16,3393
	II	0,0033		0,0227		16,3805
3	I	0,0077	0,0388	0,0107	50,0415	16,3921
	II	0,0015		0,0313		16,3446
4	I	0,0131	0,0798	0,0341	50,0260	16,3478
	II	0,0167		0,0532		16,4868
5	I	0,0127	0,0138	0,0073	50,0443	16,3885
	II	0,0070		0,0081		16,4264
Requir. acc to docum.	min.	-	-	0,20	49,80	16,350
	max.	-	-	-	50,20	16,450

Much more important is to notice that three sleeves out of tested five carriers (i.e. ten sleeves) showed lesser diameter than the minimally allowed of 16, 35 mm.

CONTROL OF DAMAGED CUTTERS

Several different cutters were examined for the purpose of control of the present damages. Besides their geometry, the cutters differ also by composition of their surface protective coating on base material (HSS steel). This protective coating is with some cutters titan nitride (TiN) and with other titan carbide (TiC). The appearance of damaged cutters is shown on photo in Figure 5.

Figure 6. shows characteristic appearance of the cracked surfaces of the cutter (broken during thread cutting).



Figure 5. The appearance of damaged cutters prior to thread cutting in the sleeve: a) thread cutters with protective coating TiN; b) thread cutters with TiC protective coating

Slika 5. Izgled ureznika oštećenih pri urezivanju navoja stezne čahure: a) ureznici sa zaštitnim slojem TiN; b) ureznici s TiC zaštitnim slojem

The detailed control of cracked surfaces of the broken cutters showed that:

- the cutters broke under an angle of 45°,
- local wrinkling of base material due to stresses over boundary of base metal tensile strength occurred,
- some cutters changed color (“turned blue”) due to overheating prior to breakage.



Figure 6. Appearance of the cracked surfaces of the thread cutter (macro record)

Slika 6. Izgled prelomnih površina ureznika (makrosnimak)

TESTING OF RAW CLAMP SLEEVES

The appearance of the not poured clamp sleeve is shown in Figure 7.a. 3D dimension control was carried out on all five raw, *as delivered*, clamp sleeves as well as hardness measurement HB 2/120/15 (due to small wall thickness $\Phi 2$ mm ball was used). After that, all sleeves were submitted to short time heating in electric furnace as to simulate conditions of heat treatment when pouring the melted Al alloy. The furnace was heated to 720 °C (temperature was additionally controlled by thermocouple NiCrNi and monitored on Honeywell device). After that the sleeves were put into furnace, held for a minute, taken out and cooled in oil to 300 °C, followed by cooling to room temperature. After sleeves cleaning, repeated 3D dimension control was car-

ried out as well as hardness measurement HB. Results of testing of sleeves prior and after simulated heat treatment are shown in Table 5.

Table 5. Results of dimension control and measurement of hardness of steel sleeves prior and after simulated heat treatment

Tablica 5. Rezultati dimenzionalne kontrole i mjerenja tvrdoće sirovih čeličnih čahura prije i nakon simuliranog toplinskog tretmana

Characteristics	Sleeves No.				
	1	2	3	4	5
Hardness* HB	271	264	274	259	268
	248	260	281	230	256
Cylindricity* /0/ mm	0,0059	0,0126	0,0143	0,0094	0,0132
	0,0158	0,0097	0,0164	0,0083	0,0119
Smallest diameter* ϕ / mm	16,4637	16,3709	16,4151	16,4063	16,3408
	16,4596	16,3653	16,4203	16,3985	16,3487

* Numerator gives information prior, while denominator specifies same after simulated heat treatment

Out of results of dimensional control it can be observed that after short time “annealing” three out of five clamp sleeves showed a reduction of the internal diameter, while the other two displayed an increase (measured differences range up to maximum 0,008 mm). It must be pointed out that these are values within measured cylindricity of the bores. Only slight decrease of hardness value has been observed, from 260 - 270 HB to ~ 230 - 260 HB. However it must be pointed out that with one of the sleeves (No. 5) bore diameter in *as delivered* status was lesser than minimally allowed.

The analysis of microstructure of cross section of *as delivered* sleeves was performed, after the simulated annealing treatment. In both cases characteristic for the ferrite - pearlite microstructure could be observed the relatively small grain size and a significant difference between marginal areas and the central cross section area could not be noticed. The microstructure of these sleeves is shown in Figure 7.b.

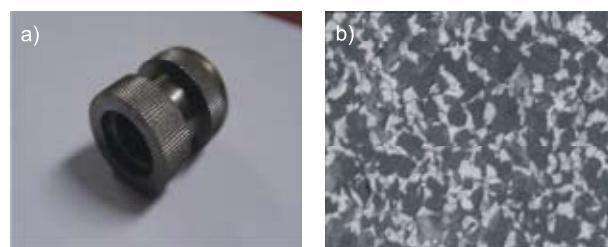


Figure 7. Clamp sleeve: a) appearance in *as delivered* condition; b) characteristic microstructure of the cross section. Magnification 220x, Nital etching

Slika 7. Stezna čahura: a) izgled u dostavnom stanju; b) karakteristična mikrostruktura na poprečnom presjeku. Povećanje 220 puta. Nagrizanje nital

RESULT ANALYSIS

It must be noticed that no significant change of microstructure at the cross section of sleeves in *as delivered status* as well as after simulated short time heat treatment in electric furnace for 1 minute has been established. To come to structural changes in steel heated at about Al temperature, it is necessary to keep such temperature for a corresponding period of time [6]. Therefore, it is understandable that the simulated heat treatment didn't lead to significant changes of microstructure, and changes of sleeve hardness value (Table 5.), consequently the same did not occur also at the pouring of Al carriers. Hardness values of such poured, raw, and shortly heat treated sleeves ranges between 230 and 270 HB. Dimensional 3D control of Al carries indicate to the following:

- perpendicularity of sleeve symmetry lines with all 5 castings lies within the boundaries of allowed tolerances,
- sleeve bore span with all 5 castings is within the boundaries of allowed tolerances,
- measured diameters of sleeve bores with 3 out of 10 controlled bores is smaller than the minimally allowed for cutting of threads $M18 \times 1,5$ mm.

Out of results of dimensional control of sleeve bore it may be concluded that short time "annealing" does not affect the internal diameter (because the measured differences range at most up to 0,008 mm, which are the values within range of those measured cylindricality of the bores). Thereby, the sleeves show only an insignificant reduction of hardness values from 260 - 270 HB to 230 - 260 HB. It is important to notice that with four out of 5 raw sleeves the smallest internal diameter is greater than allowed (Φ 16,35 mm for cutting of threads $M18 \times 1,5$ mm), whereby differences lie up to almost 0,1 mm (sleeve No. 1 and sleeve No. 2). It should be noticed that one of the sleeves (No. 5) shows already in *as delivered status* bore diameter lesser than minimally allowed.

CONCLUSION

Based on 3D control in 5 of Al carriers with clamp sleeves the following can be established:

- bore diameter measured with 3 out of 10 sleeves is lesser than that allowed for the cutting of threads $M18 \times 1,5$ mm,
- Al alloy fulfills approved norm requirements by its chemical composition and mechanical properties,
- geometrical properties of Al carriers lies within range of requirements contained in technical documentation.

With raw "as delivered" sleeves submitted additionally to "annealing" at 720 °C so as to simulate pouring conditions of Al carriers, it is important to observe the following:

- no significant reduction of bore diameter has been observed, as consequence of short time "annealing";
- three out of five sleeves had greater initial bore diameter for 0,05 to 0,1 mm than the minimally allowed for cutting of threads $M18 \times 1,5$ mm. In one case this bore was "only" ~ 0,02 mm greater than minimally allowed 16,35 mm. But with one of the sleeves measured diameter was smaller than that minimally allowed;
- with all sleeves with hardness value of ~ 270 HB in "as delivered" status, after simulated treatment in the furnace there was only insignificant reduction (from ~ 230 - 269 HB).

Based upon the inspection of delivered cutters (Figure 3.a and 3.b) it can be seen they broke (cutters 1.1; 2.1; 2.2), while the others displayed only signs of "wear" (cutters 1.2; 1.3; 1.4). Discoloration of some of the cutters caused ("turned blue"), by the overheating during thread cutting. The following can be concluded:

- because 3D control established satisfactory perpendicularity of symmetry lines of the sleeve, it is not to be expected that damaging of cutters came as result of deviation of coaxial hole;
- due to fact that cutters with surface coating TiN and TiC on HSS steel display breakage and material wear, coating itself does not affect essentially to cutter breakage.

Many of the reasons for cutter damage lie in the fact that the bore of the sleeve poses a problem of grind "drainage" during thread cutting. However, taking into account the extremely hard surface layer (TiN and TiC) on HSS steel, hardness of sleeves should not represent main reason for cutter breakage (which as a rule is the cause of scrap occurrence also with well poured Al carriers).

Cutter wear is in partly consequence of grind "drainage", but real cause of breakage with those sleeves which had smaller internal diameter than minimally allowed lies prevalently in overstress (stress above tensile strength of material), because the cutter not only enters the sleeve by cutting, it also shapes it by process of "rolling".

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