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The effect of blade thickness on microstructure and mechanical properties of ship's sand-cast propeller

Leszek Piaseczny,
Krzysztof Rogowski
Polish Naval Academy

ABSTRACT

The microstructure and resultant mechanical properties of the MM55 manganese brass applied to ship sand - cast propeller were investigated in relation to the propeller blade section thickness. It was stated that the increase of blade section thickness from 15 mm to 45 mm resulted in the increase of the volume fraction of α-phase by 5.3% and that of κ-phase by 23.7%, the decrease of the volume fraction of β-phase by 2.9%, the 0.2% proof stress $R_{0.2}$ by 11.3%, the ultimate tensile strength R_m by 5.5% and the 5.65 $\sqrt{S_o}$ elongation A_5 by 16.8%.

Keywords: blade thickness, microstructure, sand-cast propeller

INTRODUCTION

The ship propellers range in size from small (below 2 m in diameter) to large ones (above 5 m in diameter) [1].

The specimens of most ship propeller castings constitute separately cast test bars with chemical composition and mechanical properties in line with specification for propeller cast material, Fig. 1 and 2. The test bar can be also cast in the form shown by broken line in Fig. 1 [2].

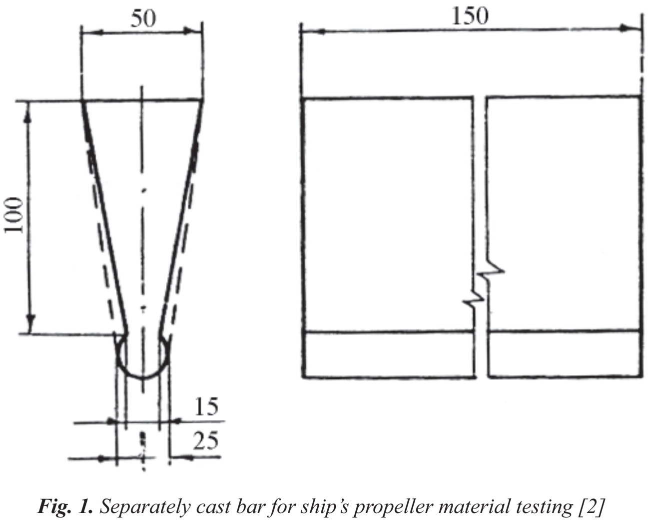

Fig. 1. Separately cast bar for ship's propeller material testing [2]

It is clear that the mechanical properties of the sand-cast ship propeller made of copper alloys, measured on a separately cast test bar, are intended for providing an assessment of general quality of the materials rather than for determination of the actual mechanical properties of the propeller casting, particularly when large sections are involved [3]. In large propeller casting with thick sections slower self-cooling rate is a hindrance from obtaining a microstructure to the effect that the mechanical properties of the propeller casting appear below these obtained from the cast test bar of only 25 mm diameter [4]. The lowest strength of the propeller casting material was found in the entrance of propeller blade into hub, Fig. 3; which is specially important for constructors [5].

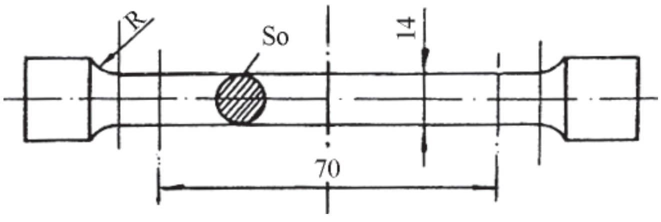

Fig. 2. Test bar for testing mechanical properties [2]

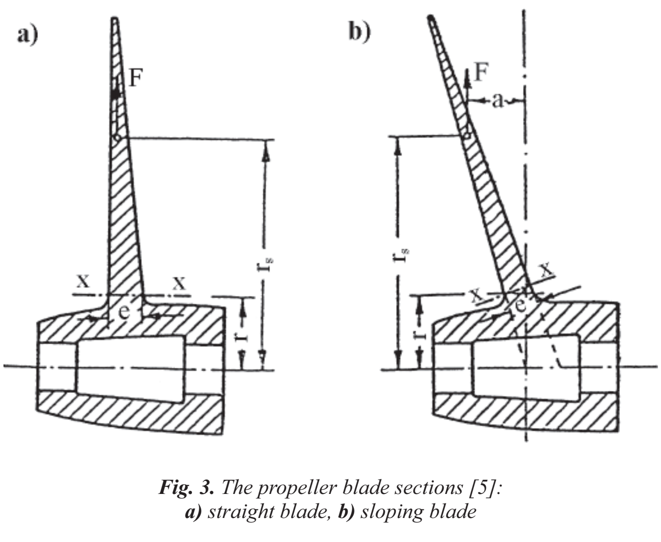

Fig. 3. The propeller blade sections [5]:
***a)** straight blade, **b)** sloping blade*

The aim of this work is to investigate changes in microstructure and mechanical properties of ship propeller blades along with increasing thickness of their sections.

TESTED MATERIAL AND TESTING PROCEDURES

The chemical composition and mechanical properties of MM55 manganese brass used for the tested ship's propeller are included in Tab. 1 where also appropriate data taken from PN-91/H-87026 standard [6] and PRS Rules [2] are attached.

The tested ship's propeller blades are 800 mm long, 15 mm thick at 0.9 R radius and 45 mm thick at 0.25 R radius. The samples for testing microstructure and mechanical properties of ships propeller's material were cut out from centre blade section of 15 mm, 20 mm, 25 mm, 35 mm and 45 mm in thickness.

***Tab. 1.** Chemical composition and mechanical properties of the tested MM55 manganese brass used for ship's propeller casting*

Item	Chemical composition [%]								$R_{0.2}$ MPa	R_m MPa	A_5 %
	Cu	Sn	Zn	Pb	Mn	Fe	Al.	Ni			
Tested material	54.5	-	41.3	0.02	3.4	1.0	0.21	-	275	488	25.6
Required by PN-91/H-87026	53-58	Max 0.5	Balance	Max 0.5	3.6-4.0	0.5-1.5	Max 0.5	Max 0.5	Min 180	Min 450	Min 15.0
Required by PRS rules	52-62	Max 1.5	35-40	Max 0.5	0.5-4.0	0.5-2.5	0.5-3.0	Max 0.5	175	440	20.0

TEST RESULTS AND DISCUSSION

The results of tensile tests are listed in Tab. 2.

***Tab. 2.** Mechanical properties of MM55 manganese brass used for the tested propeller*

Blade thickness [mm]	$R_{0.2}$ [MPa]	R_m [MPa]	A_5 [%]	HV20
15	275	488	25.6	177
20	259	482	25.8	171
25	263	484	23.6	165
35	248	477	23.1	149
45	244	461	21.3	146

The results are also graphically shown in Fig. 4.

It can be observed that along with the increasing of blade thickness the ultimate tensile strength R_m of the blade material decreased initially slowly and then quickly. Similar are the changes of the 5.65 $\sqrt{S_0}$ elongation A_5 of the material, which become stable when the blade section thickness approaches 45 mm. The 0.2% proof stress $R_{0.2}$ and hardness HV20 decreased initially quickly and became stable at the blade section thickness close to 45 mm. All the changes of mechanical properties of propeller's casting material resulted from the decreasing of self-cooling rate of propeller casting along with increasing blade section thickness.

The metalographic examinations showed that with the increasing of the blade section thickness the microstructure of the manganese brass used for the propeller casting was also changing, as presented in Tab. 3 and illustrated in Fig. 5 and 6.

***Tab. 3.** Changes of phase volume fraction in microstructure of MM55 manganese brass used for ship propeller casting, along with the increasing of blade section thickness*

Thickness [mm]	α- phase volume fraction [%]	β -phase volume fraction [%]	κ -phase volume fraction [%]
15	100	100	100
20	104.32	97.58	116.30
25	106.21	96.52	120.00
35	103.90	97.82	114.07
45	105.32	97.02	123.70

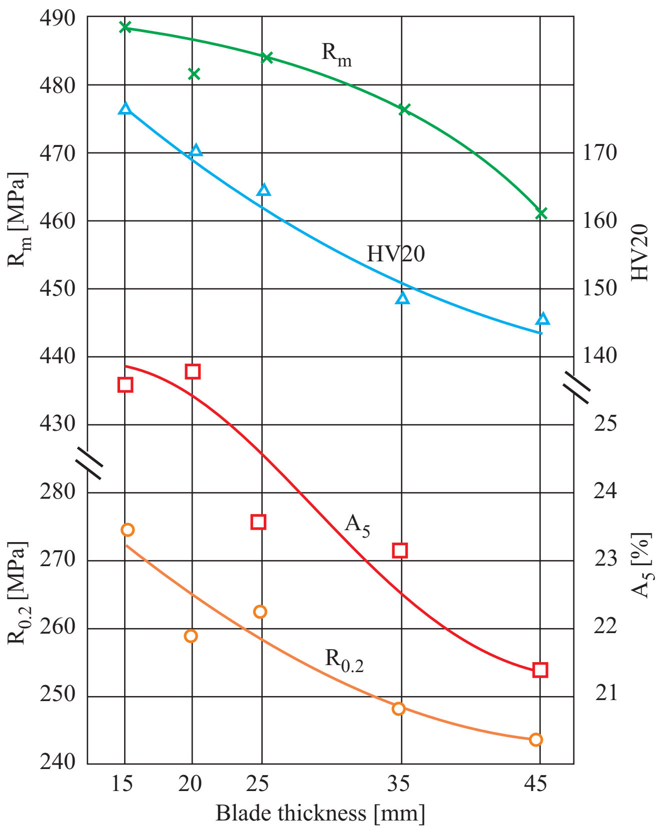

***Fig. 4.** Changes of mechanical properties of MM55 manganese brass used for ship propeller casting in function of increasing blade section thickness*

The increase of the blade section thickness resulted not only in the volume fraction of the phase in microstructure but also in the increased areas of α-phase precipitates. Fig. 7

shows the number of α -phase precipitates in relation to thickness of propeller blade section. It can be observed that in the microstructure the number of precipitates of 0-500 μm² area diminished and that of precipitates of 1001-5000 μm² are increased along with decreasing self-cooling rate.

The course of microstructure changes in MM55 manganese brass used for ship propeller casting resulted from the decreasing of self-cooling rate of casting along with the increasing of blade section thickness.

Fig. 5. *Micrograph of MM55 manganese brass used for ship propeller casting, at the blade section of 15 mm in thickness. Magnification : 240x.*

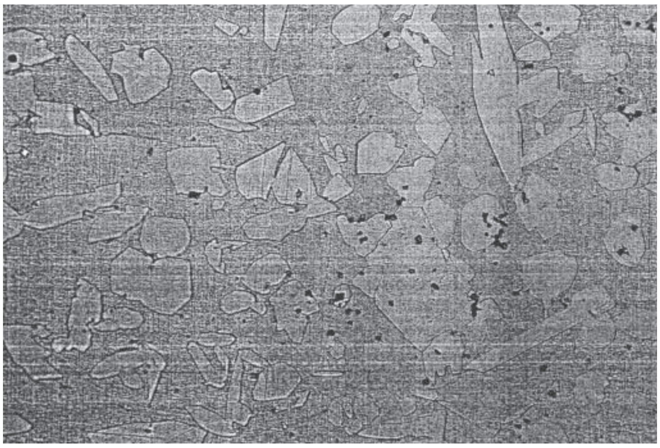

Fig. 6. *Micrograph of MM55 manganese brass used for ship propeller casting, at the blade section of 45 mm in thickness. Magnification : 240x.*

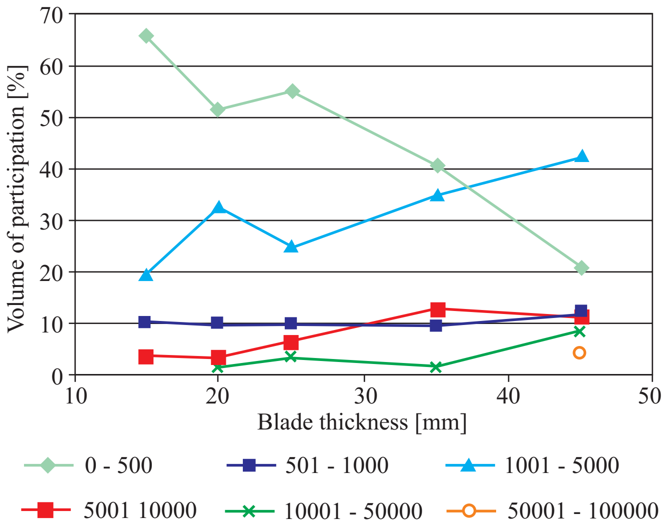

Fig. 7. *Volume of precipitation in relation to thickness of ship propeller blade section*

CONCLUSIONS

The performed tests showed that the increasing - from 15 mm to 45 mm - of blade section thickness of the ship sand - cast propeller made of MM55 manganese brass resulted in :

- An increase of the volume fraction of hard and short κ- phase in the material's microstructure, and a simultaneous decrease of the mechanical properties of the material.
- The following decrease of particular properties was observed : the 0.2% proof stress $R_{0.2}$ – by 5.3%, the ultimate tensile strength R_m –by 5.5 %, $5.65\sqrt{S_o}$ elongation A_5 - by 16.8%, and HV20 hardness - by 17.5%.

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CONTACT WITH THE AUTHORS

Prof. Leszek Piaseczny
Mechanic-Electric Faculty,
Polish Naval University
Śmidowicza 69
81-103 Gdynia, POLAND
e-mail : lpias@amw.gdynia.pl

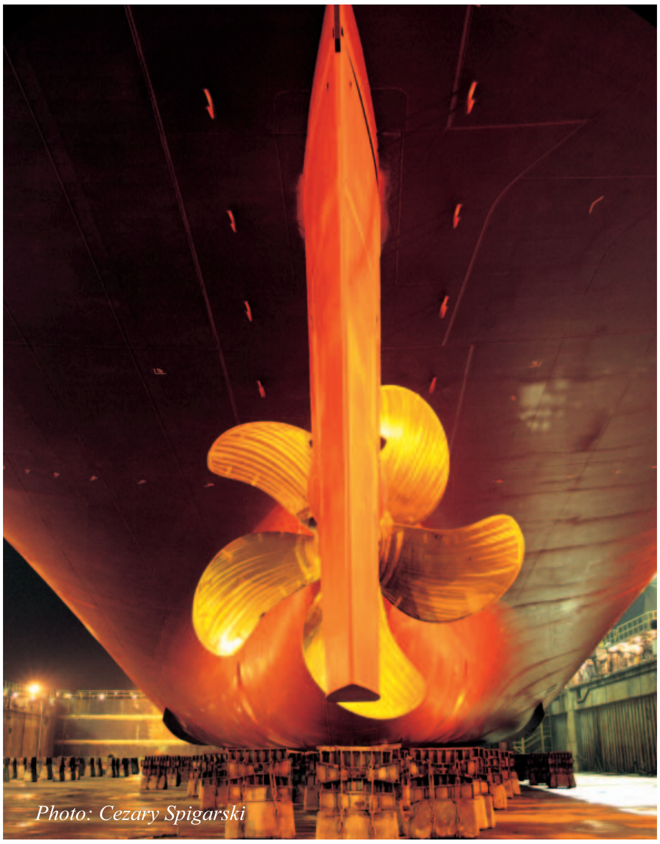

Photo: Cezary Spigarski