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THE INFLUENCE OF POURING TEMPERATURE ON THE MICROSTRUCTURE AND FLUIDITY OF ELEKTRON 21 AND WE54 MAGNESIUM ALLOYS

WPŁYW TEMPERATURY ODLEWANIA NA MIKROSTRUKTURĘ I LEJNOŚĆ STOPÓW MAGNEZU ELEKTRON 21 I WE54

The influence of pouring temperature on the fluidity, microstructure and hardness of modern magnesium alloys containing rare earth and zirconium (Elektron 21) and yttrium (WE54) was investigated in the paper. The experimental data showed that the pouring temperature influenced the fluidity of these alloys, which is one of the most important properties of cast alloys. In the case of Elektron 21 alloy the relationship between the pouring temperature and the fluidity was typical for metallic alloys, whereas in WE54 magnesium alloy, the decrease of the fluidity above 780°C was observed. The volume fraction of intermetallic phases and hardness of the Elektron 21 and WE54 alloys did not depend on the pouring temperature.

Keywords: Magnesium alloy, Elektron 21 alloy, WE54 alloy, fluidity, microstructure

W pracy przedstawiono wyniki badań wpływu temperatury odlewania nowoczesnych stopów magnezu zawierających metale ziem rzadkich (Elektron 21) i itr (WE54) na lejność, mikrostrukturę i twardość. Na podstawie uzyskanych rezultatów stwierdzono, że temperatura odlewania wpływa na lejność badanych stopów. W przypadku stopu Elektron 21 obserwowano charakterystyczną dla materiałów metalicznych zależność pomiędzy lejnością a temperaturą odlewania. W stopie WE54 stwierdzono zmniejszenie lejności przy temperaturze odlewania wyższej od 780°C. Udział objętościowy faz międzymetalicznych występujących w badanych stopach i ich twardość nie zależą od temperatury odlewania.

1. Introduction

Mg-Y-Nd magnesium alloys are characterised by high strength and good creep resistance advantageous in automotive and aerospace applications [1]. The Mg-Y-Nd system provides a combination of mechanical and corrosion properties, which allowed the development of commercial alloys: WE43 and WE54 [2]. The rare earth elements have beneficial effect on creep properties, thermal stability of structure and mechanical properties of magnesium alloys [3]. The Mg-Y-Nd alloys serve the aerospace market well. However, these alloys have a high cost of production due to the high cost of yttrium and difficulties in casting [4]. Therefore there is need for an alternative alloy which has similar properties to Mg-Y alloys, but with foundry handling and associated costs like non-yttrium containing alloys [5]. Elektron 21 is a new magnesium based sand casting alloy predicted to work up to approximately 200°C. It has high strength, good corrosion resistance and castability, similar to Mg-Y-Zr alloys [4].

The fluidity is one of the most important properties of cast alloys. The quality of castings is influenced by the fluidity of liquid metal, especially under gravity casting conditions. The pouring of metal into the mould is one of the critical steps in founding, since the fluidity of the liquid and its subsequent solidification and cooling determine whether the cast shape will be properly formed, internally sound and free from defects [6]. The fluidity is defined as the ability of a molten metal to flow through and to fill a mould cavities before solidification occurs. The fluidity is an empirical property, which depends on the composition of the molten alloy, casting temperatures and mould properties [7].

The castability is also affected by reactions with the molten metal, oxide formations and reactions with containment materials, lubricants and mould coating [8]. Purity of molten alloys also influences mould filling capacity and it has been found that dissolved gases, intermetallic precipitates, inclusions, and non-metallic impurities reduce the fluidity of alloys [9]. In particular, oxide films, which spontaneously form at the surface of

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reactive melts, increase their surface tension and reduce their ability to reproduce sharp details. These films can break and mix into the flowing stream, thereby decreasing the effective fluidity of the melt. Oxides were found to reduce fluidity by as much as 20% [7].

2. Experimental

The materials for the research were WE54 and Elektron 21 magnesium alloys. Their chemical composition is provided in Table 1.

TABLE 1

Chemical composition of the WE54 and Elektron 21 alloys

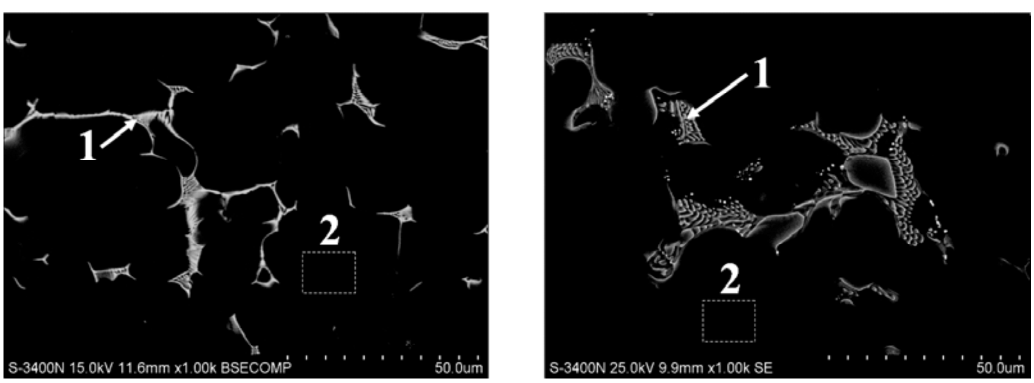
Alloy	Nd	Gd	TRE	Y	Zr	Zn	Mn	Fe	Mg
WE54	1.7	–	1.9	5.0	0.55	<0.01	<0.01	0.002	balance
Elcktron 21	2.7	1.2	4.2	–	0.49	0.4	0.001	0.003	balancc

Fluidity has been investigated by determining the flow length with a mould featuring a spiral shaped cavity. Casting in sand moulds has been done at different melt temperatures from 720°C up to 820°C. The phase identification of the alloys was conducted by X-ray diffraction (JDX-75) using Cu K radiation. For microstructural observations, an OLYMPUS GX 71 metallographic microscope and a HITACHI S-3400N scanning electron microscope with a Thermo Noran EDS spectrometer equipped with SYSTEM SIX were used. The specimens were prepared by the standard technique of grinding and polishing. For a quantitative description of the structure, stereological parameters describing the size and shape of the solid solution grain and phase precipitations were selected. To measure the stereological parameters, a program for image analysis "MET-ILO" was used. Hardness tests were performed with a Vickers indenter (HV3).

3. Results and discussion

3.1. Microstructure of sand cast Elektron 21 and WE54 magnesium alloys

SEM micrographs of the as-cast alloys is shown in Fig. 1, from which it can be seen that the as-cast microstructure of the alloys consists of α-Mg matrix and second phase crystallizing along the grain boundaries in the form of divorced eutectics.



Pt	Chemical composition at.-%		
	Mg	Nd	Gd
1	90.1	7.4	2.5
2	99.7	0.3	

a)

Pt	Chemical composition at.-%				
	Mg	Y	Zr	Nd	Dy
1	93.1	4.1	-	2.7	0.2
2	98.9	2.0	0.1		

b)

Fig. 1. The SEM images and EDS results of Elektron 21 alloy (a) and WE54 alloy (b)

The results of EDS microanalysis showed that the second phase in the Elektron 21 alloy was composed of magnesium, neodymium and gadolinium (point 1, Fig. 1a), however, precise determination of magnesium content in the second phase was difficult, due to the interaction between the electron beam and magnesium matrix.

The solid solution contained small amount of neodymium (point 2, Fig. 1a). In the WE54 magnesium alloy the intermetallic phase consisted of magnesium, yttrium, neodymium and small amounts of dysprosium (point 1, Fig. 1b).
The XRD analyses were performed to identify the phases existing in the alloys studied and the results are shown in Fig. 2 and 3. It can be seen that the Elektron 21 alloy consisted of two phases, the α-Mg matrix and Mg_3Gd intermetallic compound. Based on the results of chemical microanalysis, the molecular formula of the phase can be written as $Mg_3(Gd,Nd)$.
The XRD pattern of the WE54 alloy revealed that the alloy consisted of α-Mg solid solution and Mg_5RE phase (Fig. 3).

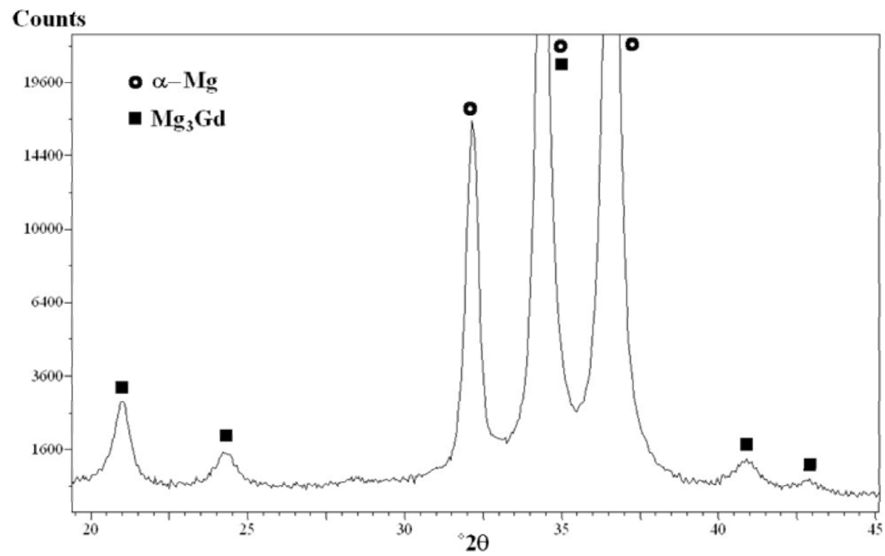


Fig. 2. XRD pattern of sand cast Elektron 21 alloy

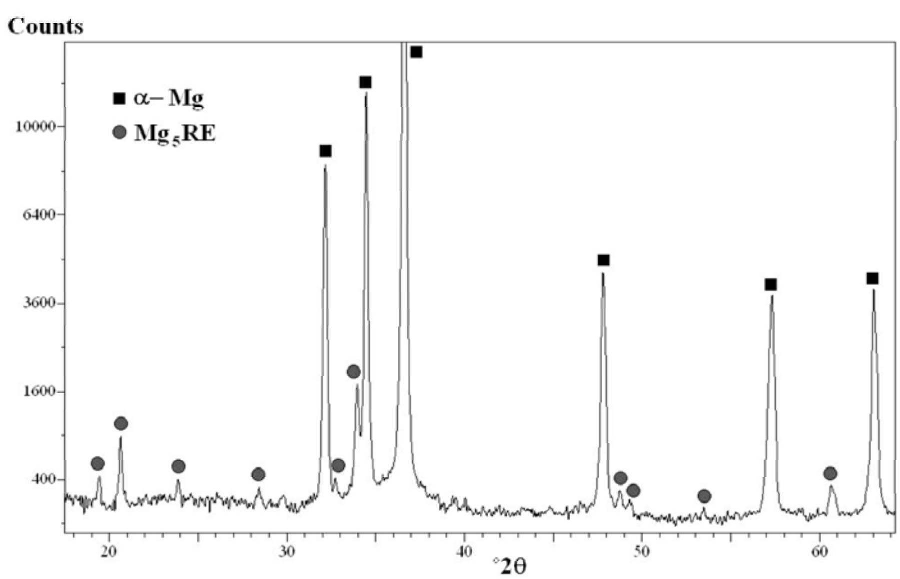


Fig. 3. XRD pattern of sand cast WE54 alloy

3.2. The effect of pouring temperature on the fluidity

The pouring temperature of metallic alloys into the mould is one of the critical factors in founding, since the fluidity of the liquid and its subsequent solidification and cooling determine, whether the cast shape will be properly formed, internally sound and free from defects [6]. Fig. 4 shows the influence of pouring temperature on the fluidity of Elektron 21 and WE54 magnesium alloys. Fluidity can be expressed by the distance that molten metal has flown during filling and solidification.

For the Elektron 21 magnesium alloy, its filling length increases with increasing pouring temperature. In the case of WE54 magnesium alloy, its filling length increases slowly when the pouring temperature rises from 720 to 780°C, and decreases slowly when the pouring temperature increases from 780 to 820°C. The fluidity of WE54 is much better than that of Elektron 21 magnesium alloy. Generally, a better fluidity in higher temperature is connected with the decreasing viscosity and surface tension of molten metal with the increase of pouring temperature, which leads to the increasing filling speed. At the same time, the heat capacity of molten magnesium alloy rises with increasing temperature of pouring, what results in the increase of filling time. On the other hand, the oxidation liability of magnesium alloy increases with casting temperature, which will increase the viscosity and decrease the filling length. This effect is insignificant within the investigated range of pouring temperature for the Elektron 21 magnesium alloy. In the case of WE54 magnesium alloy the fluidity decreases, when the temperature surpass 780°C. This is connected with the presence of inclusions and oxide films in the microstructure of WE54 alloy poured at 830°C (Fig. 5).

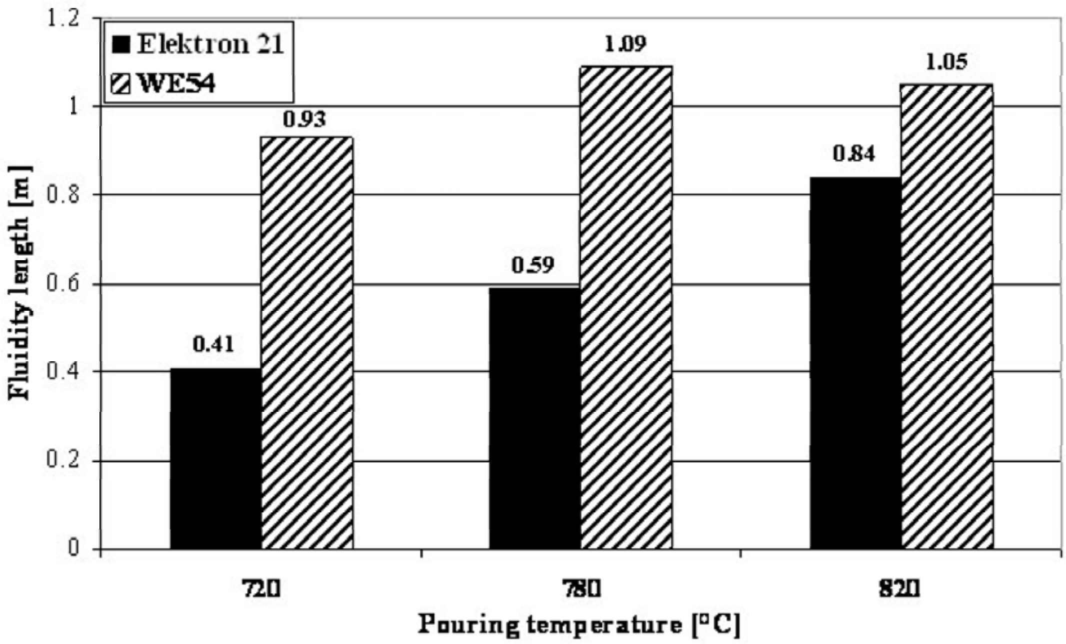


Fig. 4. The influence of casting temperature on the fluidity length of Elektron 21 and WE54 alloys

a) b)

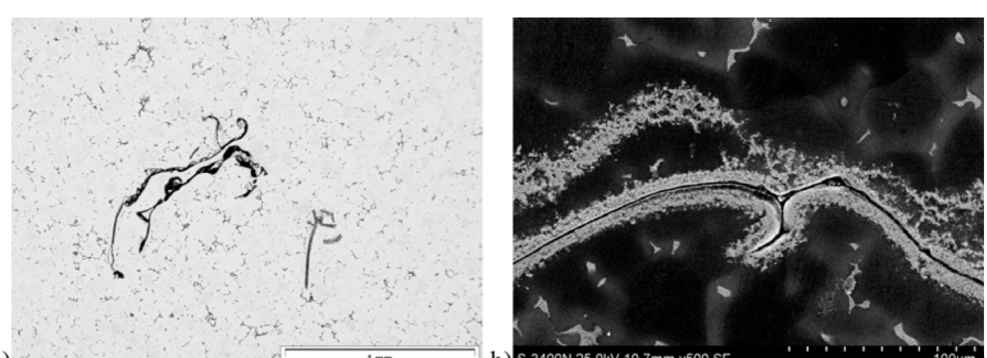


Fig. 5. Oxide films in WE54 magnesium alloy after sand casting from 830°C, a) LM, b) SEM

3.3. The influence of pouring temperature on the microstructure

Microstructures of Elektron 21 alloy and WE54 alloy after casting at different temperatures are shown in Fig. 6 and Fig. 7, respectively. In each case the microstructure of the alloys consists of solid solution α-Mg surrounded with a discontinuous network of $Mg_3(Gd,Nd)$ compound in the Elektron 21 alloy and Mg_5RE phase in WE54 alloy. The pouring temperature also does not effect the phase composition of Elektron 21 and WE54 alloys. Table 2 shows the results of quantitative metallography as a function of pouring temperature and associated coefficients of variation. One can see in Table 2, that the area fraction of Mg_3(Gd,Nd) and Mg_5RE phases does not change fundamentally with the increase of the casting temperature within the range studied here.

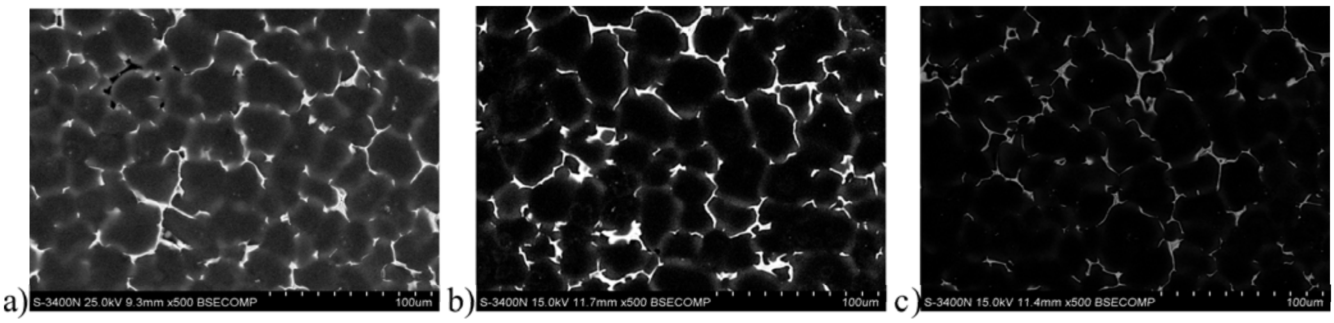


Fig. 6. Microstructure of Elektron 21 alloy after casting a 720 °C (a), 780 °C (b) and at 820 °C

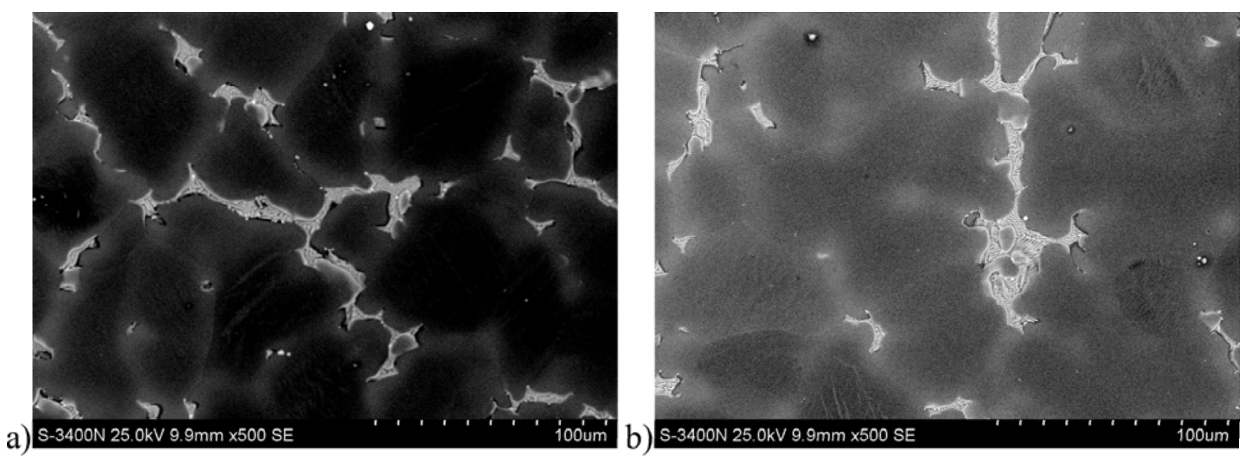


Fig. 7. Microstructure of Elektron 21 alloy after casting at 720 °C (a), and at 820 °C (b)

TABLE 2

The influence of pouring temperature on the area fraction of intermetallic compounds in Elektron 21 and WE54 alloys

Alloy	Parameter	Pouring temperature [°C]		
		720	780	820
Elektron21	Area fraction of Mg_3(Gd,Nd) [%]	2.5	2.6	2.5
	Coefficient of variation [%]	185	171	166
WE54	Area fraction of Mg_5RE [%]	3.2	3.2	3.3
	Coefficient of variation [%]	128	142	127

The statistical analysis was used in order to verify the obtained results (Tab. 3). The measurements of area fraction in each sample were performed on 20 random images. Distributions of area fraction were analyzed by Shapiro-Wilk test and in each case Gaussian distributions were observed. It enabled the application of homogeneity test of several means with Bartlett's test for equality of variances. The results obtained in the tests exhibited unequivocally that pouring temperature did not influence mean values of area fraction of intermetallic compounds in Elektron 21 and WE54 alloys.

TABLE 3

The results of statistical analysis obtained for measurements of area fraction of Mg_3(Gd,Nd) in Elektron 21 alloy and Mg_5RE in WE54 alloy

Alloy	Elektron 21			WE54		
Pouring temperature [°C]	720	780	820	720	780	820
Area fraction	2.5	2.6	2.5	3.2	3.2	3.3
Shapiro-Wilk (α = 0.05) (W (α/2,n); W(1 -α/2,n))	(0.802; 0.983)	(0.802; 0.983)	(0.802; 0.983)	(0.816; 0.982)	(0.816; 0.982)	(0.816; 0.982)
W	0.84	0.89	0.85	0.98	0.95	0.90
Bartlett	p = 0.45 (α = 0.05)			p = 0.56 (α = 0.05)		
Test the homogeneity of several means	p = 0.92 (α = 0.05)			p = 0.49 (α = 0.05)		

In the samples of WE54 alloy taken from gating system of spiral cast the grain size (grain diamater) rose with the increasing casting temperature (Fig. 8). In the case of Elektron 21 alloy grain size increased slightly with the increasing of the pouring temperature.

Non-gaussian distribution of measured grain diameter was observed in each sample. Therefore, non-parametric Kruskall-Wallis test was performed to compare the obtained results. The statistical comparison showed a significant differences among the samples poured at different temperatures for the WE54 alloy. Thus, the pouring temperature influenced the grain size of WE54 alloy. The grain size rose with the increase of the casting temperature due to longer time of self-cooling of casting mould (lower cooling rate). However, in the case of Elektron 21 alloy non-parametric Kruskall-Wallis showed that differences in grain size between samples poured at different temperatures were not significant.

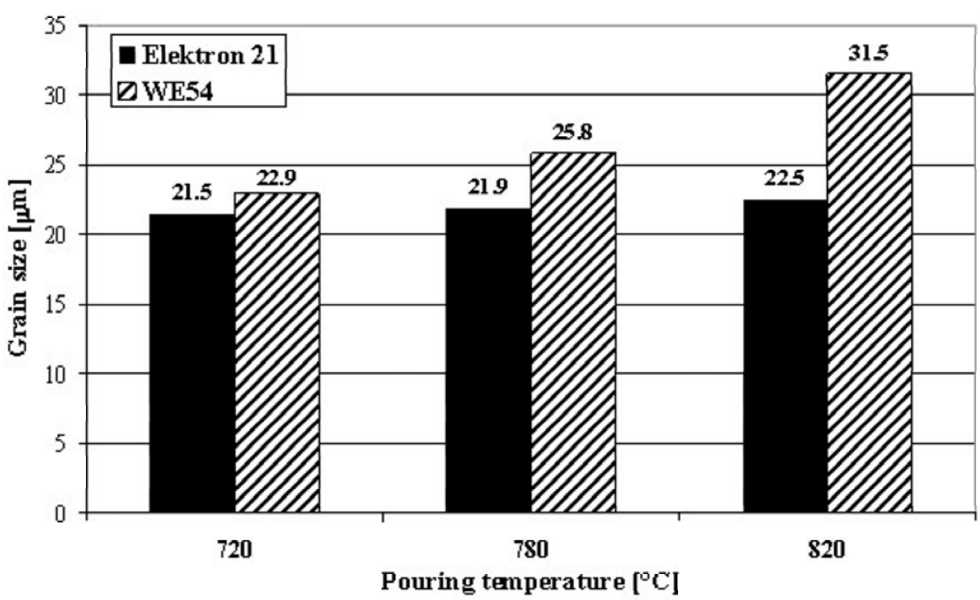


Fig. 8. The influence of pouring temperature on grain size of Elektron 21 and WE54 alloys

3.4. The influence of pouring temperature on the hardness

Fig. 9 shows the Vickers hardness as a function of pouring temperature for investigated alloys. It is seen that the Vickers hardness does not depend on the pouring temperature for both alloys. Insignificant differences between hardness of particular samples poured at variable temperatures was confirmed by statistical analysis (test the homogeneity of several means). Although the grain size of WE54 is higher than that of Elektron 21 alloy, the hardness of WE54 alloy is higher than that of the Elektron 21 alloy. It can be explained by solid solution strengthening of WE54 alloy (Fig. 1) and higher volume fraction of intermetallic compound (Tab. 2) in comparison with the Elektron 21 alloy.

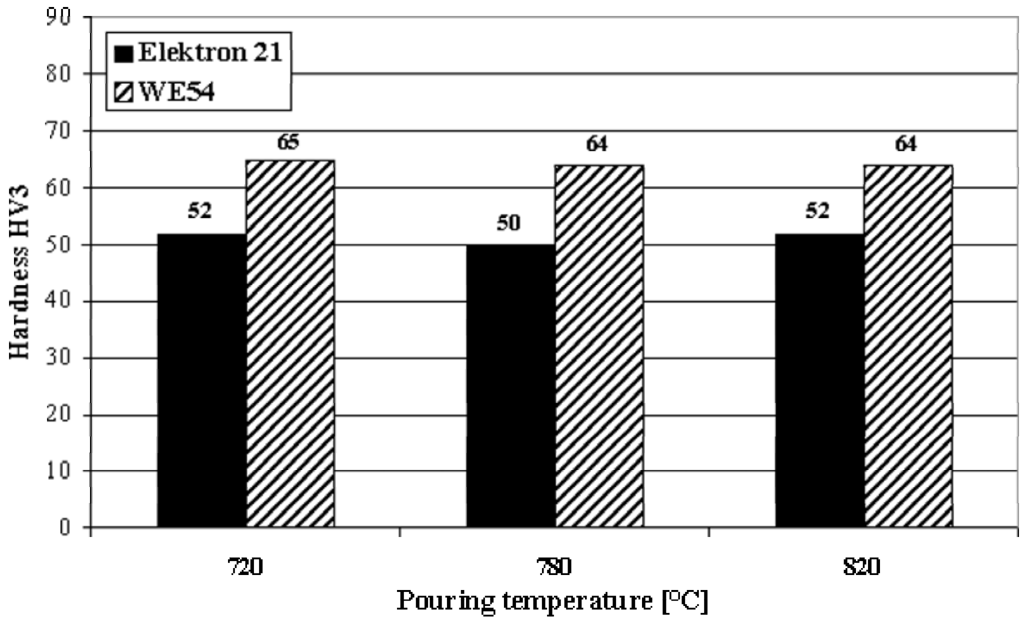


Fig. 9. Vickers hardness of Elektron 21 and WE54 alloys as a function of pouring temperature

4. Conclusions

The influence of pouring temperature on the microstructure and fluidity of Elektron 21 and WE54 magnesium alloys have been investigated the following conclusions can be drawn:

1) The fluidity of Elektron 21 magnesium alloy increases with the increase of pouring temperature from 730°C to 830°C. The fluidity of WE54 increases when the casting temperature increases from 720°C to 780°C and decreases when the pouring temperature is higher than 780°C.
2) The microstructure of sand-cast Elektron 21 alloy consists of α-Mg and $Mg_3(Gd,Nd)$ intermetallic compound. The microstructure of WE54 alloy consists of α-Mg and Mg_5RE phase. The volume fraction of these intermetallic compounds does not depend on the pouring temperature.
3) The decrease of pouring temperature of WE54 alloy results in the decrease of grain size. In the case of Elektron 21 alloy the relationship between the grain size and casting temperature was not observed.
4) The change of pouring temperature has no influence on the hardness of WE54 and Elektron 21 alloys.

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