MODERN TYPES OF PVD/PACVD COATINGS USED FOR INJECTION MOLDS AND THEIR EFFECTS ON SELECTED PHYSICAL PROPERTIES OF MOLD CAVITIES

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Abstract

This research paper deals with an effect of injection mold core/cavity surface and their additional treatment on selected optical properties and surface quality of these tool parts. Used mold cavities were made from tool steels 1.2343 (chromium-molybdenum-vanadium-silicon steel with good hardenability) and 1.2083 (martensitic steel with high chromium content), their surface was polished to the roughness of Ra = 0.08 microns (manufacturer guaranteed mirror finish). For purposes of an experiment, injection mold with interchangeable core/cavities was designed and manufactured. Subsequently, simple shape cavities were manufactured (plates with dimensions of 120 x 120 mm) and further were provided with a specific coating in order to change surface properties. In total, three types coatings were applied; CrN, AlTiN and hydrogenated a-C:H coatings. All cavities were measured using 3D non-contact roughness tester in different areas in cavity (totally 8 areas per cavity were selected in various distances from polymer inlet). Specifically, surface gloss under different reflection angles with respect to coating or tool steel type was evaluated from optical properties. The results show that the additional surface treatment of injection mold cavity with coatings can reduce the values of roughness parameters, however, affect the level of core/cavity gloss.

Keywords: Injection mold, coating, surface gloss, surface roughness, mold cavity

1. INTRODUTICTION

In tool designs for plastic processing various materials are used. While for low-batch production the tools are made from aluminum or copper alloys in mass production tools from steel are preferred. Steel is made by simply adding a small percentage of carbon to iron ore. To improve final properties of steel alloying elements are added. The list of most important element in tool steel is listed in **Table 1**. [1, 2]

Table 1 Alloying elements and their effect on steel properties [1, 3]

The Element	The Effect
Carbon	0 - 0.765 % - linear increment of hardness, 0.766 - 2.14 % - dominant increment of wear
Manganese	Increases deeper hardening abilities
Silicon	Adds strength and toughness
Chromium	Adds wear resistance, toughness and corosion resistance
Nickel	Adds toughness and some wear
Tungsten	Adds wear resistance
Vanadium	Refines grain structure
Molybdenum	Adds heat resistance and hardenability
Sulfur, Lead, Phosporus, Calcium	Imparts better machinability

In plastic processing the high temperature of plasticized material, corrosion and high abrasion by fillers may leads to damage of tool surface. The optimization of properties of martensite matrix and type and distribution of hard particles is required. For improvement of surface wear resistance e.g. PVD coating or hard chroming is used. [4, 5]

Wear of steel during injection molding is not a simple function of surface hardness, but it is more complex issue (**Figure 1**). [6] Therefore for optical parts it is necessary to obtain as high surface resistance as possible to avoid any scratches and decreases of gloss.

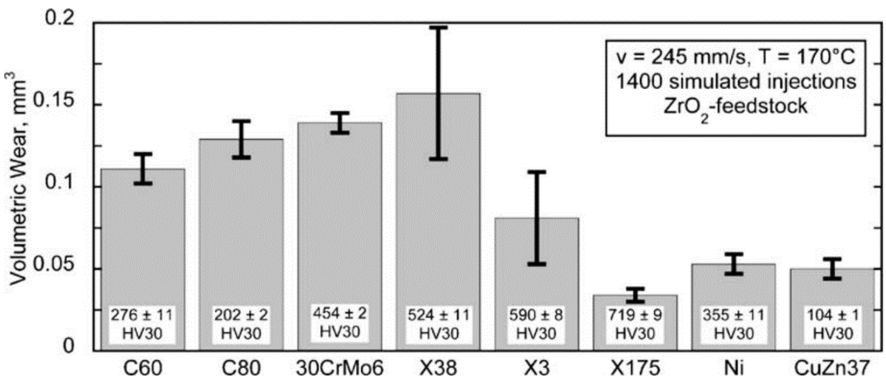

Figure 1 Volumetric wear of selected tool steels [6]

The aim of presented paper is to investigate the influence of PVD/PACVD coatings on surface roughness parameters and specular gloss of injection cavities. The possibility to replace usually used tool steel by another conventional tool steel without a need of cavity coating for specific plastic production with respect to mentioned properties is also evaluated.

2. MATERIALS AND METHODS

For cavities of the injection molds used in the research, 1.2343 tool steel is very often used, however from the point of view of the material composition (low Cr content), it is not suitable for the injection of aggressive plastics (e.g. PVC and PC). As an alternative to this steel type, 1.2083 mold steel, which contains more than 12% Cr, was chosen due to its structure and excellent polishability.

All coating types were applied to the polished surface of mold cavities with the roughness of approximately Ra = 0.08 µm, manufactured from 1.2343 mold steel. From all available coating types, applied by CVD, PACVD, and PVD technologies, were based on recommendations selected three types of coatings. First type was CrN coating of silver grey color with coating temperature from 150 to 450 °C. AlTiN violet color coating with application temperature of 600 °C was selected on a second place. Last coating type was hydrogenated a-C:H coating of black color with coating temperature between 160 - 300 °C. Selected properties of used coating are given in following table (**Table 2**).

Table 2 Selected properties of individual coating types [8]

Cavity material / coating type	Micro hardness HV 0.025	Coating thickness (µm)	Friction coefficient (-)
1.2343 tool steel	-	-	-
1.2083 tool steel	-	-	-
1.2343 + CrN coating	1500 - 2500	1 - 10	0.4
1.2343 + AlTiN coating	2500 - 3500	1 - 6	0.4
1.2343 + a-C:H coating	2000 - 4000	1 - 3	0.05 - 0.15

Figure 2A contains injection mold insert with two highly polished mold cavities. Moreover, **Figure 2B** shows the mold cavity sample and eight locations (green rectangles) on which 3D roughness measurements were conducted. Two areas, namely number 1 and 8, i.e. the area closest (1) and the farthest (8) area from the polymer inlet into the cavity (blue arrows) were selected for the evaluation. Furthermore, red rectangles depict areas of surface gloss measurements.

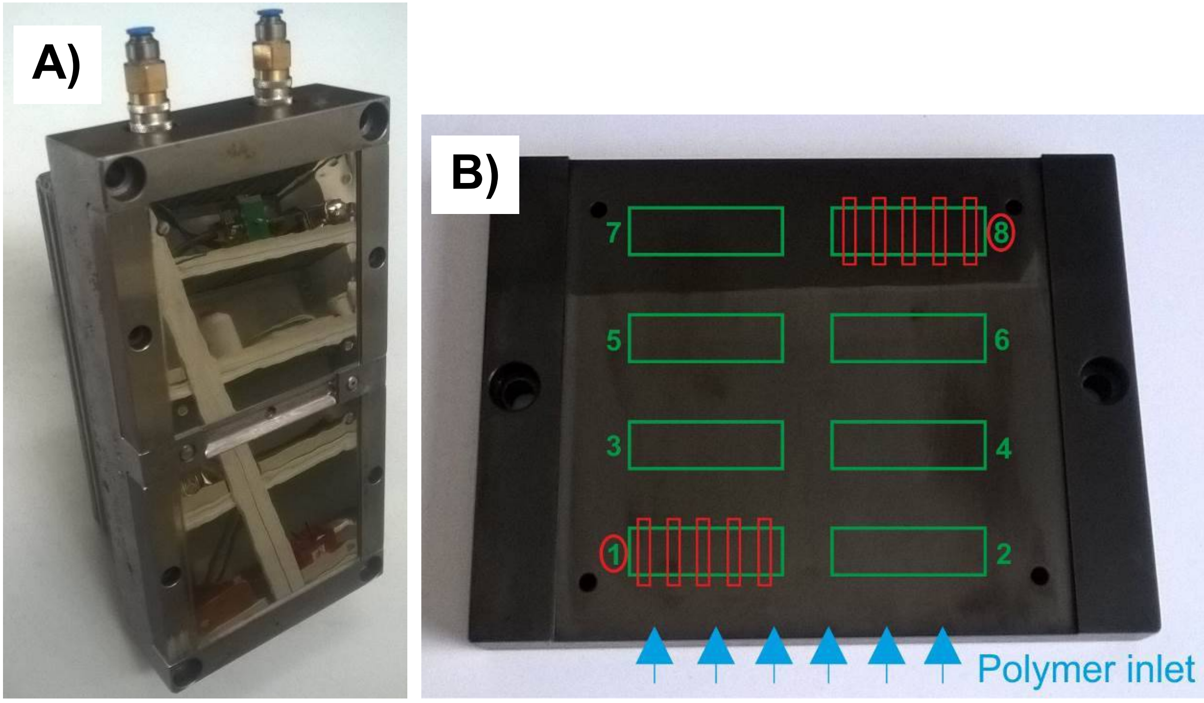

Figure 2 Injection mold; A) Mold insert with two cavities, B) Single mold cavity

Surface quality measurement was performed and evaluated according to EN ISO 4287 on 3D device Talysurf CLI500 having the resolution of 1 nm using the Taylor Hobson software. For the measurement, eight areas with dimensions of 27.5 x 7.5 mm were selected, where these locations were at different distances from the polymer inlet (film gate system). The measurement itself was carried out at a speed of 500 µm / s, where the total measuring time of one area was approximately 5 hours. Totally three surface roughness parameters were evaluated; Ra (µm) - arithmetical mean roughness value, Rz (µm) - greatest height of the roughness profile, and RSm (µm) - mean peak width.

Surface gloss (specular gloss) measuring was performed and evaluated according to ASTM D523 and D2457 using NHG268 gloss meter of 3nh Company. This device enables to measure specular gloss at three measurement angles: 20°, 60°, and 85°. All gloss test were conducted at room temperature of 28 °C, at normal daylight. Measuring areas differ for individual angles, gloss meter measures at area of 10 x 10 mm for 20°, 9 x 15 mm for 60°, and 5 x 36 mm for 85°. Every area on cavity (also in total 8 areas per cavity) was tested five times. [7]

3. RESULTS AND DISCUSSION

Results from 3D roughness measurements are depicted in tables in **Figure 3**. Term 1-EW (East-West) corresponds to the arithmetic mean of the measured results in the x-axis, while 1-NS (North-South) shows the results for y-axis measurements. Comparing results for both tool steels, it is apparent that 1.2083 tool steels achieves using the same technological operations better values for all roughness parameters, especially in Rz parameter obtained in the x-axis in areas closer to the polymer gate system (1-EW). An interesting fact is that using the same production technologies and process conditions result in different parts of the same simple shape cavity into different roughness - Ra (cavity of 1.2343 tool steel), when the values of this parameter varies by nearly 1/3.

	1.2343	Mean	Std. Dev.	Min	Max
1 - EW	Ra	0.324	0.029	0.241	0.395
	Rz	1.574	0.139	1.151	2.054
	RSm	0.379	0.027	0.315	0.477
1 - NS	Ra	0.482	0.295	0.131	1.141
	Rz	2.617	1.478	0.799	5.767
	RSm	0.154	0.016	0.112	0.222
8 - EW	Ra	0.271	0.021	0.218	0.325
	Rz	1.382	0.103	1.103	1.665
	RSm	0.300	0.015	0.257	0.351
8 - NS	Ra	0.274	0.074	0.158	0.508
	Rz	1.576	0.414	0.888	2.909
	RSm	0.150	0.014	0.110	0.209

	1.2083	Mean	Std.Dev.	Min	Max
1 - EW	Ra	0.121	0.014	0.086	0.147
	Rz	0.647	0.086	0.440	0.823
	RSm	0.207	0.010	0.178	0.231
1 - NS	Ra	0.131	0.025	0.091	0.428
	Rz	0.819	0.173	0.558	2.739
	RSm	0.124	0.016	0.089	0.204
8 - EW	Ra	0.236	0.023	0.194	0.315
	Rz	1.267	0.126	0.996	1.874
	RSm	0.203	0.009	0.176	0.231
8 - NS	Ra	0.211	0.035	0.140	0.518
	Rz	1.273	0.230	0.779	3.115
	RSm	0.145	0.013	0.111	0.190

	1.2343 + CrN coating	Mean	Std. Dev.	Min	Max
1 - EW	Ra	0.254	0.016	0.216	0.312
	Rz	1.398	0.120	1.130	1.858
	RSm	0.207	0.009	0.182	0.233
1 - NS	Ra	0.219	0.021	0.163	0.448
	Rz	1.318	0.194	0.958	2.743
	RSm	0.157	0.013	0.123	0.209
8 - EW	Ra	0.260	0.019	0.206	0.316
	Rz	1.453	0.138	1.091	2.102
	RSm	0.207	0.010	0.182	0.240
8 - NS	Ra	0.224	0.020	0.176	0.508
	Rz	1.380	0.195	0.998	3.253
	RSm	0.158	0.013	0.121	0.211

	1.2343 + AlTiN coating	Mean	Std. Dev.	Min	Max
1 - EW	Ra	0.114	0.022	0.057	0.137
	Rz	0.485	0.097	0.319	0.985
	RSm	0.210	0.011	0.190	0.256
1 - NS	Ra	0.079	0.007	0.060	0.136
	Rz	0.469	0.073	0.343	1.131
	RSm	0.169	0.017	0.124	0.248
8 - EW	Ra	0.164	0.024	0.103	0.239
	Rz	0.890	0.145	0.554	1.581
	RSm	0.213	0.010	0.187	0.251
8 - NS	Ra	0.140	0.026	0.094	0.293
	Rz	0.837	0.188	0.494	1.912
	RSm	0.162	0.016	0.121	0.236

	1.2343 + a-C:H coating	Mean	Std. Dev.	Min	Max
1 - EW	Ra	0.164	0.031	0.098	0.228
	Rz	0.967	0.181	0.562	1.429
	RSm	0.213	0.010	0.187	0.246
1 - NS	Ra	0.141	0.014	0.105	0.222
	Rz	0.903	0.143	0.586	1.991
	RSm	0.162	0.014	0.122	0.222
8 - EW	Ra	0.163	0.031	0.107	0.219
	Rz	0.956	0.185	0.620	1.380
	RSm	0.214	0.011	0.187	0.239
8 - NS	Ra	0.142	0.017	0.105	0.222
	Rz	0.915	0.176	0.586	1.860
	RSm	0.161	0.013	0.136	0.213

Figure 3 Results of 3D roughness measurements

However, the main task was to compare the influence of various coatings on the roughness parameters applied on same base material (1.2343 tool steel). Only minimal change in Ra parameter was identified for cavity with CrN coating, whose measured parameters are worse than those measured for cavity manufactured from 1.2083 mold steel. The Ra parameters varied up to a maximum of approximately 15 %. A more significant improvement in surface roughness parameters was observed for the cavity with a-C:H coating, where Ra roughness was improved, i.e. reduction of nearly 30 % in roughness was identified. The same reduction is also apparent for Rz parameters. After application of coating on the mold cavity, the lowest values of surface roughness parameters were measured for cavity coated with AlTiN. In this case, roughness reduction of up to 50 % was measured, which is a significant improvement in surface quality.

The values of surface specular gloss measured at three different angles are showed in tables in **Figure 4**. Based on obtained values, it was confirmed that for highly polished surfaces it's necessary to measure at the highest possible measurement angle on device (in our case - 85°). As can be seen from the tables (**Figure 4**), higher specular gloss was identified for steel 1.2083 compared to 1.2343 steel using identical production technologies and parameters. The lowest reduction in surface gloss after application of coating (about 10 %) is evident for CrN-coated cavity. Furthermore, coated cavity, for which the lowest surface roughness was measured (1.2343 + AlTiN coating), showed the reduction of gloss in comparison to an uncoated cavity by almost 15 %. The lowest values of specular gloss were measured for a-C:H coated cavity, where the decreased by almost 20 % to an average of 97 GLU in comparison to the uncoated cavity was identified.

	1.2343	Mean	Std. Dev.	Min	Max
1	20°	927,4	17,1	902,1	950,0
	60°	514,5	2,6	509,7	517,5
	85°	118,7	3,1	113,5	121,3
8	20°	967,7	17,7	939,7	992,3
	60°	529,5	1,6	526,9	531,3
	85°	121,9	0,5	121,4	122,6

	1.2083	Mean	Std. Dev.	Min	Max
1	20°	1069,0	34,3	1015,0	1115,0
	60°	550,6	1,2	549,0	552,3
	85°	121,5	0,4	121,1	122,1
8	20°	955,8	14,7	940,1	978,2
	60°	537,6	1,4	535,8	539,8
	85°	127,2	1,2	125,0	128,6

	1.2343 + CrN coating	Mean	Std. Dev.	Min	Max
1	20°	387,7	12,8	371,1	402,1
	60°	303,2	2,3	300,1	306,6
	85°	107,7	0,2	107,5	107,9
8	20°	429,5	105,8	343,7	637,7
	60°	300,1	4,3	295,0	306,1
	85°	107,2	0,2	107,0	107,6

	1.2343 + AlTiN coating	Mean	Std. Dev.	Min	Max
1	20°	171,5	14,3	151,4	194,2
	60°	164,4	6,9	153,8	174,5
	85°	102,5	0,7	101,5	103,4
8	20°	178,9	20,7	138,1	196,2
	60°	172,9	8,1	156,7	177,5
	85°	103,7	0,3	103,5	104,2

	1.2343 + a-C:H coating	Mean	Std. Dev.	Min	Max
1	20°	138,6	9,0	122,7	148,7
	60°	132,2	4,0	124,4	135,9
	85°	96,4	1,8	93,0	98,0
8	20°	148,7	15,8	129,3	172,1
	60°	137,9	7,3	130,8	149,2
	85°	97,1	0,9	95,7	98,2

Figure 4 Results of specular gloss for individual mold cavities in GLU (Glass Unit)

4. CONCLUSION

In the research, application of selected coating types in injection mold cavities and their influence on surface roughness parameters and optical properties (specular gloss) has been evaluated. The results indicate that traditionally used tool steel is replaceable at almost the same cost by highly polished steel without the need to use modern coatings. On the other hand, as was already mentioned, PVD/PACVD coatings can affect many other parameters, such as plastic product demolding, sliders sliding properties, etc. Surface roughness measurement using 3D method showed that AlTiN and a-C:H coatings change cavity roughness parameters -> improve surface quality. On contrary, CrN coating applied on cavity did not bring a significant change in quality. In the case of optical properties, namely specular gloss changes, it has to be stated that the application of coating into the cavity of the injection mold reduces its specular gloss and hence the gloss of resulting polymeric part.

In order to apply results in practice and make final conclusions, it is necessary to focus research on the plastic parts itself and determine to what extent the selected coatings applied in the mold cavity affect the surface quality and gloss of these products.

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