

Potential Laser Processing Parameters for Obtaining Milk Repelling Surface on Stainless Steel (AISI 316L)

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Abstract—In the previous authors review article it was confirmed, that the use of hydrophobic surfaces in the food industry is becoming more frequent, and new technologies for creating such surfaces are being developed. Among many available and developing technologies, further authors research is linked with laser radiation made hydrophobic surface on food grade stainless steel (AISI 316L). Many articles were found where researchers proved efficiency of laser made hydrophobic surface interaction with water, but none found where such surface interact with milk. Since milk is a water suspension of different substances (mostly animal fat and proteins), it is much complex fluid, that requires special handling for its processing and preserving. It follows from this, that milk has slightly different physical properties, that can affect its interaction with different hydrophobic surfaces. As no data was found about such interaction, this article main aim is to check free accessible laser processing parameters for obtaining water hydrophobic surface on stainless steel and find out if these parameters are usable for further research, but with milk. First experiments already have shown promising results and may be a start point for searching of most suitable laser processing parameters, in order to get most efficient milk repelling surface on stainless steel.

Keywords— *Milk repelling surface, laser treatment, stainless steel, food industry.*

I. INTRODUCTION

Use of hydrophobic surfaces in food industry is getting wiser due to its useful effects. As reviewed in authors previous article, nowadays most common way to obtain food safe hydrophobic surface is by applying coat of natural wax. This wax surface no only repels water and solutions, but also oil and emulsions. Also, high temperature durability, allows to use wax-based coatings for interaction with hot beverages (tea or coffee), that is

why this method is mostly used in single use paper cups or dishes [1], [2]. Other methods are being researched and developed too, since wax coatings require continuous replacement and still can contaminate product that is in contact with it [3].

Passive repelling surfaces, where effect is obtained by base material itself, but with modified surface structure. No regular resurfacing is required, which cuts down maintenance costs and excludes risk of product contamination. These surface structure modifications commonly are obtained by chemical, electrochemical etching or mechanical treatment. These methods still require resources and special tools, as laser treatment gives more controllable and better-quality surfaces. Laser made water and oil repelling or attracting structures on different material structures are current day field of new research and discoveries. [4]

Since water and machine oil are most common fluids used in different machines, engines and transmissions, most researches are made in these fields. Other fluid substances, such as milk and alcohol, are left aside, since food industry are more keen on traditional processing technologies [5]. Willing to explore unknown grounds, author started own research on milk repelling stainless steel surface, that could be obtained by laser processing [6].

As milk is water suspension with animal fats and proteins, it is complex fluid that requires special handling in order to process and preserve it. Also, milk has different physical properties and it may influence on its interaction with hydrophobic surfaces, differing it from regular water. All this must be taken in account, to guarantee that milk remains safe and unchanged after interacting with repelling surface, no contamination is allowed. These requirements may be reason, why up to this day, no more detailed

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researches were made to figure out if laser treated hydrophobic stainless-steel surface could even be used for milk processing or storage. [7]

First step in these research series, is checking if already known laser treatment parameters for obtaining hydrophobic surface on stainless steel are applicable for milk. Several articles were examined where researchers obtained hydrophobic surface on stainless steel using laser systems, that are similar to authors available ones. Multiple surface samples were made, that was visually tested for its hydrophobic properties not only with water, but also with milk “Table 1 - 2”.

TABLE 1

Laser processing parameters used for obtaining hydrophobic surface on AISI 316L stainless steel (1)			
Parameter	Reference		
	[8]	[9]	[10]
Pulse power	3 W	0.22 mJ	10 W
Spot size	50 μm	30 μm	n/a
Scan distance	50 μm	50 μm	60 μm
Scan speed	600 mm/s	150 mm/s	500 mm/s
Pulse time	120 ns	40 ns	50 ns
Rate	50 kHz	25 kHz	20 kHz
Water contact angle	160°	169°	158°

TABLE 2

Laser processing parameters used for obtaining hydrophobic surface on AISI 316L stainless steel (2)			
Parameter	Reference		
	[11]	Test sample 1	Test sample 2
Pulse power	20 W	5 W	16 W
Spot size	21 μm	n/a	n/a
Scan distance	100 μm	10 μm	70 μm
Scan speed	150 mm/s	200 mm/s	10 mm/s
Pulse time	220 ns	30 ns	50 ns
Rate	25 kHz	80 kHz	200 kHz
Water contact angle	>150°	>150°	>150°

II. MATERIALS AND METHODS

For surface treatment, diode-pumped, q-switched fiber laser ROFIN PowerLine F20 Varia with auto focus platform was used. Large roll of 0.5 mm thick AISI 316L

stainless steel was laser cut (Suntop ST-FC1390) in smaller 50x50 mm blank pieces. Test pieces remain their original surface finish, as there were no deep scratches and corrosion signs. Using Rofin laser system own software, required treatment parameters were specified in treatment area of 5x5 mm. Several test surface samples were made using not only data from articles “Table 1 - 2”, but also making own discovered parameters (polished surface effect) “Fig. 1”.

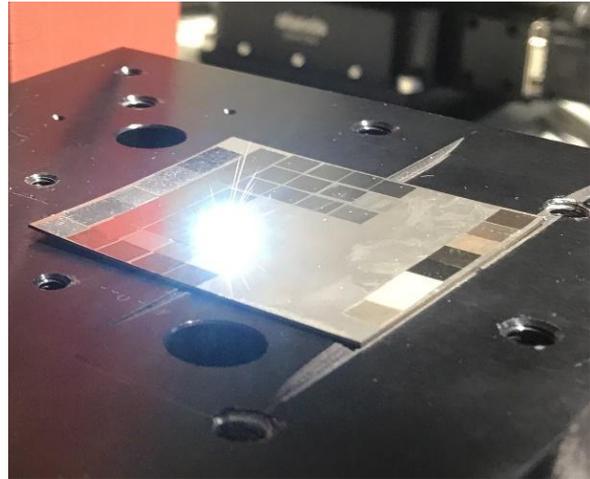


Fig. 1. Laser processing of AISI 316L stainless steel blank piece.

Each modified surface area was tested by placing 20 microlitre drinking water or 3,5% fat pasteurised cow milk droplet using precise laboratory pipette (Gilson-pipetman p100) and visually examined for hydrophobic effect “Fig. 2”.



Fig. 2. Laser processing of AISI 316L stainless steel blank piece.

Droplet placing test was regularly repeated for each day for 14-day period in order, to check time-changing effects. After each visual examination, samples were cleaned with dish soap and water, and later dried in air, only first few times paper towel was used to soak moisture.

For gained surface analysis, 3d measuring laser microscope Olympus Lext OLS5000 was used. Microscope system provided not only high-quality colour picture, but also created 3d map of surface, where software calculated its roughness “Fig. 4”.

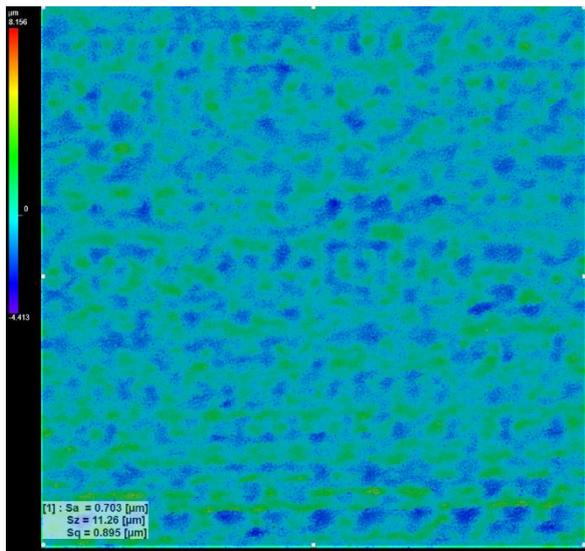


Fig. 3. Laser made hydrophobic surface "heat map" and software calculated roughness parameters.

III. RESULTS AND DISCUSSION

In other author articles provided laser processing parameters have indeed proved, that they are usable for obtaining hydrophobic surfaces on stainless steel. All test surface samples have similar visual appearance as non-reflective dark surface with clearly visible rough structure. During first 2 days of water and milk droplet placing, test surfaces have shown super-hydrophilic effect (Contact angle $<10^\circ$), attracting fluid and immediately spreading it across whole area. With each next day, hydrophilic effect started shift to more hydrophobic, and remaining unchanged after day 7 "Fig. 4" [12].

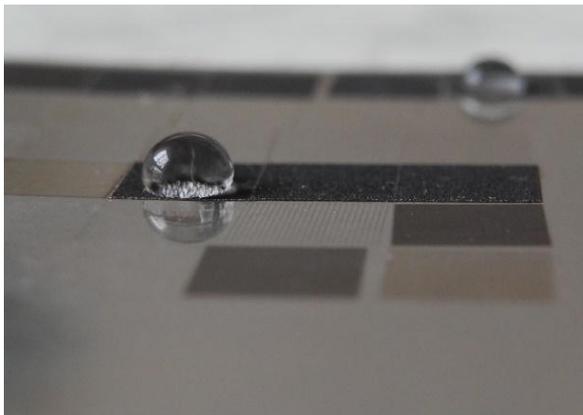


Fig. 4. Water droplet on laser made hydrophobic surface.

Unfortunately, other article mentioned laser processing parameters did not provide identical results, as there was no super-hydrophobic effect observed (Contact angle $>150^\circ$). Test surfaces have shown better hydrophobic effect (Contact angle 90° - 150°) with water droplets, meantime milk clearly performed less hydrophobic "Fig. 5". Such results could be explained by differences in laser systems and used material itself as well.

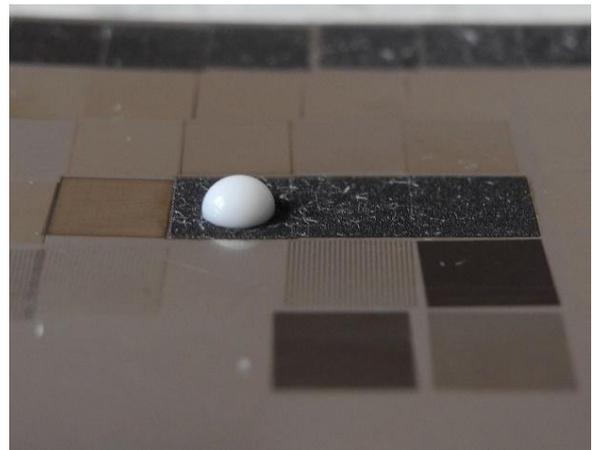


Fig. 5. Milk droplet on laser made hydrophobic surface.

Despite achieving more less desired result – laser made hydrophobic surface on stainless steel, further handling of test samples have shown certain disadvantages, that may exclude such surface structure use in food industry. Main problem appears, as test surface is wiped with any kind of organic material (paper, cloth or even fingertip) leaves residue stuck in hydrophobic structure, technically working as sandpaper "Fig. 6".

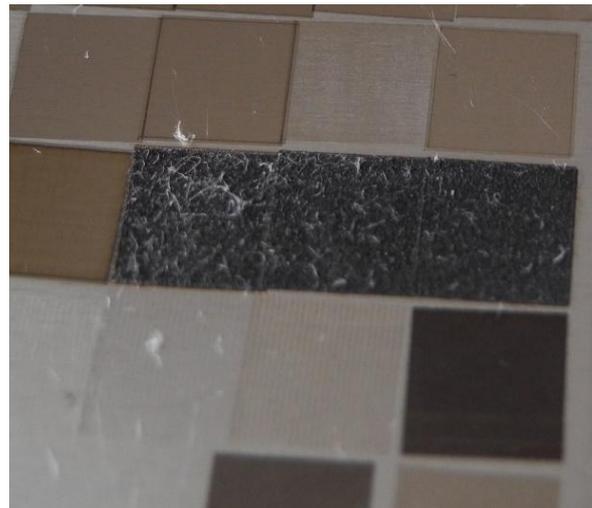


Fig. 6. Organic material residue on laser made hydrophobic surface.

Other unwanted effect was observed as milk droplet leaves stain areal even after it was washed away with sufficient amount of water, meaning that some milk solids tend to stuck inside hydrophobic structure itself "Fig. 7".

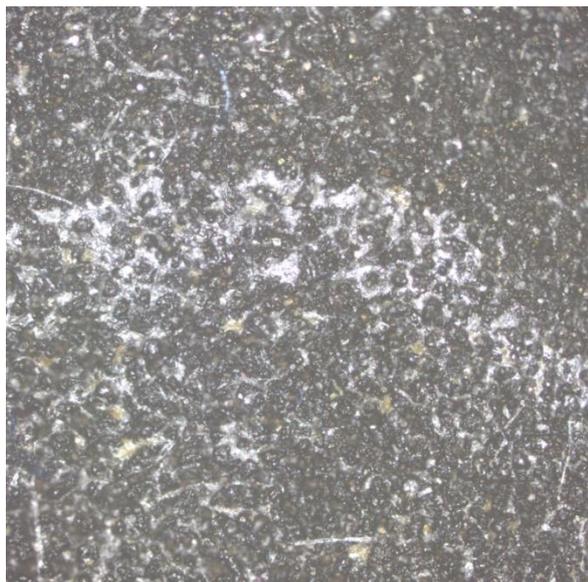


Fig. 7. Milk solids (white) in laser made hydrophobic surface structure.

Such effects are not acceptable from microbiological safety side, as any potential conditions that could contribute to pathogen microflora growth must be avoided [13], [14]. This behaviour could be explained by surface structure geometry, that resembles mountains with peaks, making surface abrasive “Fig.8” [15].

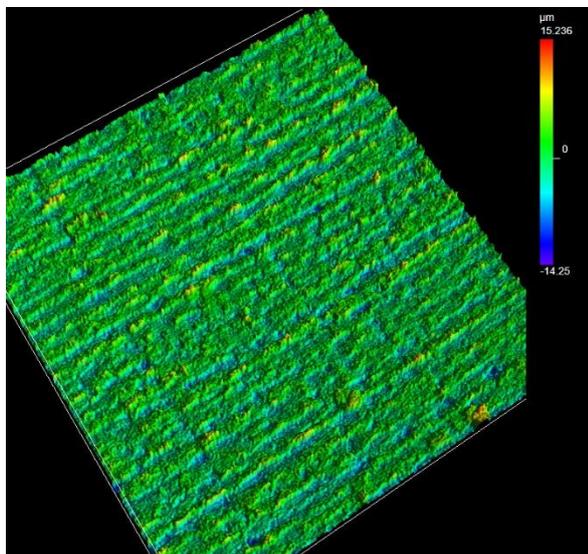


Fig. 8. Laser made hydrophobic surface structure under microscope.

Other laser processing parameters were tested out in order to create and test polished effect surface on stainless steel, as polished surfaces provide quite sufficient microbiological safety, as there are less chances for residue to attach. Test polish effect surfaces “Fig. 9” provide almost no hydrophobic properties, but shows better results, leaving none visible milk stains after surface washing with water [16].



Fig. 9. Comparison of laser “polished” (left) and untreated surface (right).

Direct comparison of laser made hydrophobic and laser “polished” surfaces clearly show their difference in roughness “Fig. 10”:

- Laser “polished” surface
 - Sa – 1.073 μm
 - Sz – 21.448 μm
 - Sa – 1,382 μm
- Laser made hydrophobic surface
 - Sa – 8.416 μm
 - Sz – 106.774 μm
 - Sa – 10,664 μm

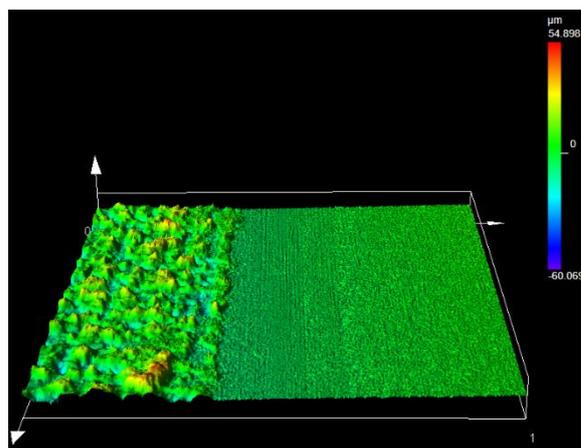


Fig. 10. Microscopic structure comparison of laser “polished” (right) and laser made hydrophobic surfaces (right).

IV. CONCLUSIONS

Theoretical use of laser made hydrophobic surfaces on stainless steel is very perspective for food industry, but as this research shows, there are many requirements that must be considered in order to provide microbiological safety. Worlds many decades long experience in food processing equipment production and use proves, that polished

surfaces provide sufficient safety and cleanliness. Nowadays laser processing can provide high quality surface polishing of stainless steel, so this way of technology should be considered for future development and use.

Also, there still may be possibility to achieve both smooth and hydrophobic surface on stainless steel, but by creating dimpled structure, that would be made and tested in future researches [17].

Finally, from personal experience, it is clear, that in laser processing it is quite problematical to achieve identical results if different laser systems are used. Each equipment unit requires its own corrections in processing parameters in order to achieve desired results. Processed material composition and its pre-processed surface finish also influences end result and may require some corrections in parameters.

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