Fabrication of high-performance wafer-scale lubricants-retaining Ni mold for defect-free production of microfluidic chips

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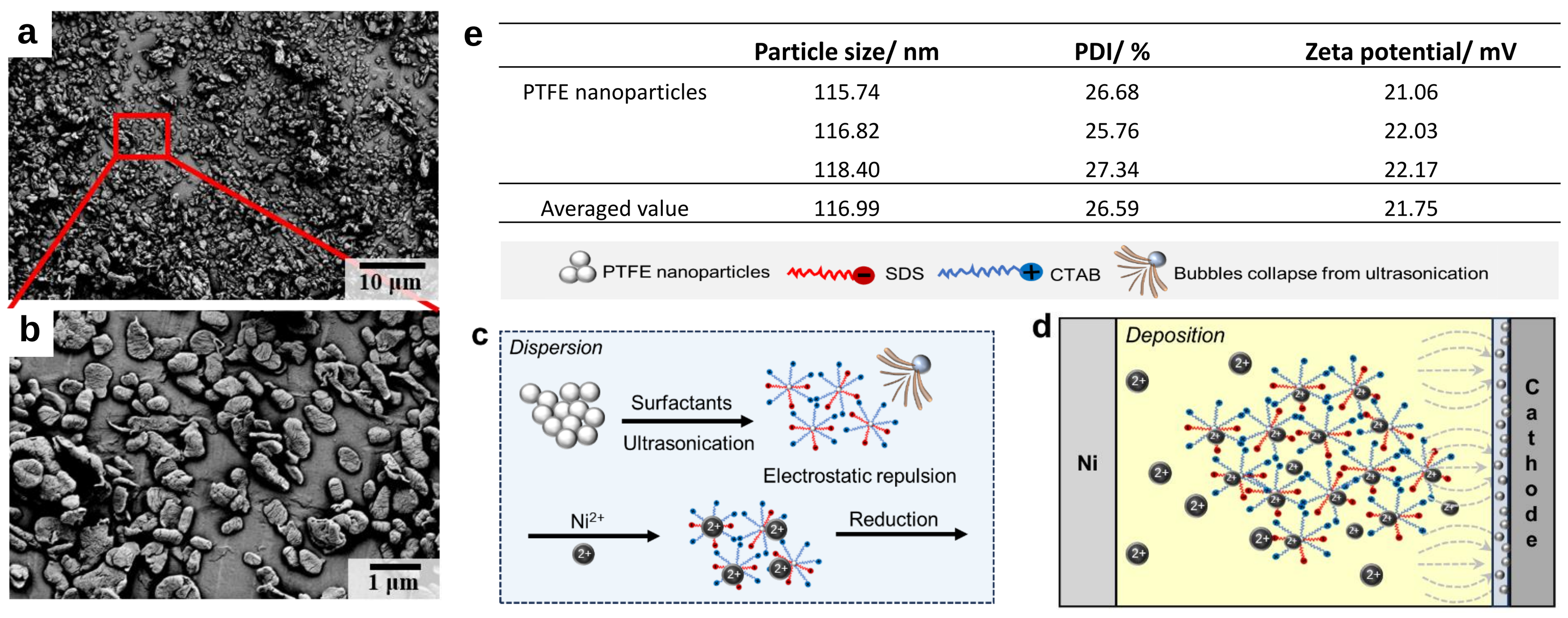
❖ Motivation

- To reduce the demolding defects on the polymer workpieces during micro injection molding.
- To reduce the adhesion and friction forces between nickel molds and polymers, we co-deposit lubricating PTFE nano-fillers into the nickel matrix by one-pot electrodeposition.
- To disperse these hydrophobic nanoparticles in the divalent nickel electrolyte, we optimize the formulation of surfactants and nanoparticles.
- To evaluate the mechanical and tribological performance of nickel-PTFE mold, microhardness test and pin-on-disc test have been conducted, with the coefficient of friction (COF) and wear morphology detected.
- To evaluate its surface roughness, surface wettability against the polymer melts, and surface energy to reveal its lubrication mechanism.
- To validate its lubrication properties via AFM tapping mode and demolding force measurement during injection molding for over 1500 cycles.
- To assess whether the PTFE nano-fillers can be pulled out and cause contamination to the polymer chips and meanwhile evaluate its biocompatibility.

❖ Dispersion and formulation

- Cationic surfactant CTAB and anionic surfactant SDS modified and dispersed PTFE nanoparticles in the nickel sulphamate electrolyte solution.
- PTFE nanoparticles have a diameter of around 100 nm to 300 nm as powder, and this diameter has been reduced to 117 nm under the effects of surfactants and ultrasonication.



	Particle size/ nm	PDI/ %	Zeta potential/ mV
PTFE nanoparticles	115.74	26.68	21.06
	116.82	25.76	22.03
	118.40	27.34	22.17
Averaged value	116.99	26.59	21.75

Fig. 1. SEM images of PTFE nano-fillers as powder (a & b); the mechanism of nanoparticle dispersion and co-deposition (c & d); the particle size, PDI and zeta potential of PTFE nanoparticles in the electrolyte (e).

❖ Fabrication process

- UV-lithography was performed to fabricate the silicon wafer with micro features.
- The metallization of the silicon wafer was achieved by sputtering titanium and nickel vanadium on its surface.
- After co-deposition, silicon wafer was etched by KOH solution and photoresist was removed to expose the surface of the mold.
- Micro structured Ni (Fig. 3(a) and (c)) and Ni-PTFE molds (Fig. 3(b)) have star patterns with a height of 100 µm and a width ranging from 30 µm to 110 µm.

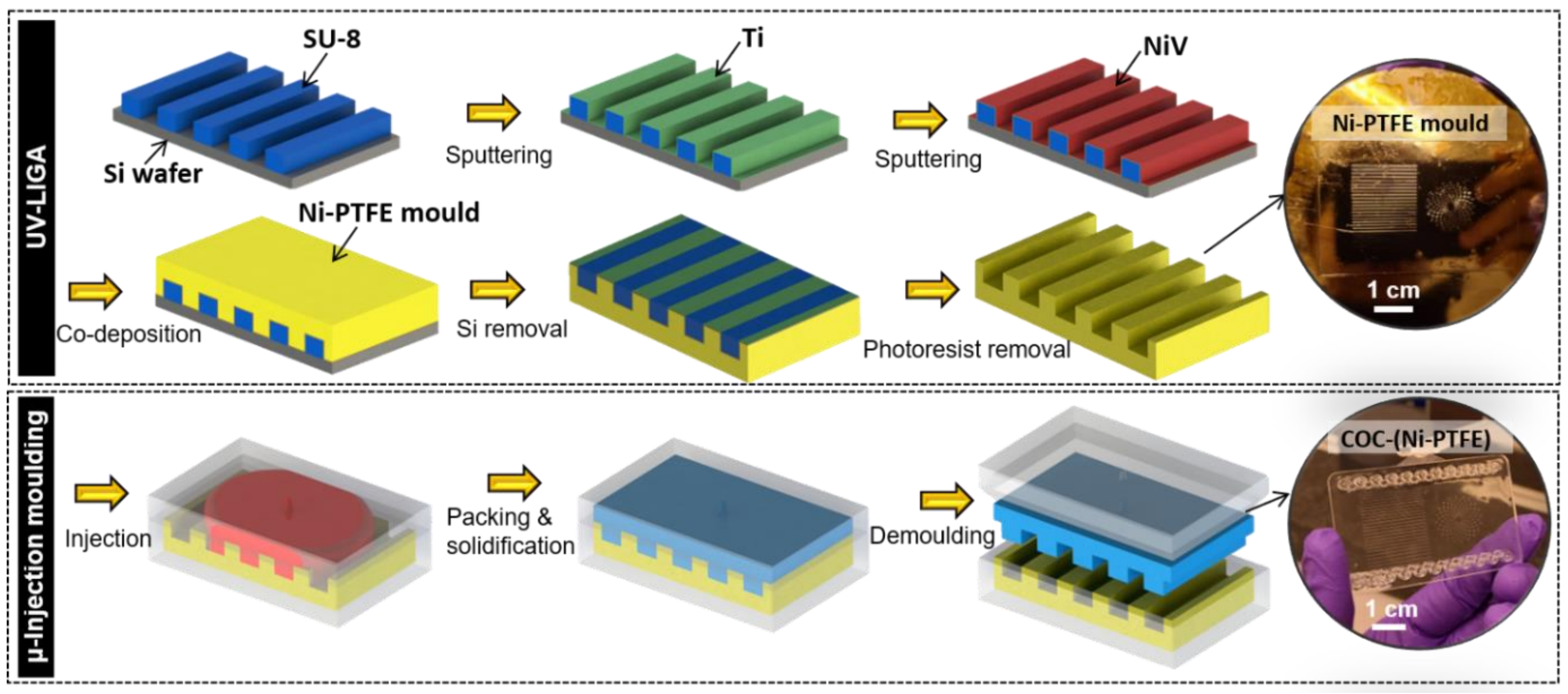


Fig. 2. The fabrication process of Ni-PTFE nanocomposite mold, and the electroformed Ni-PTFE mold with the produced COC chip from micro injection molding process.

❖ Micro injection molding

- Micro channels (30 µm wide and 100 µm deep) in the COC, PP and PMMA demolded from Ni mold showed severe pile-up and damaged sidewall. In comparison, COC chips injection-molded from Ni-PTFE mold had good surface quality and structural integrity.

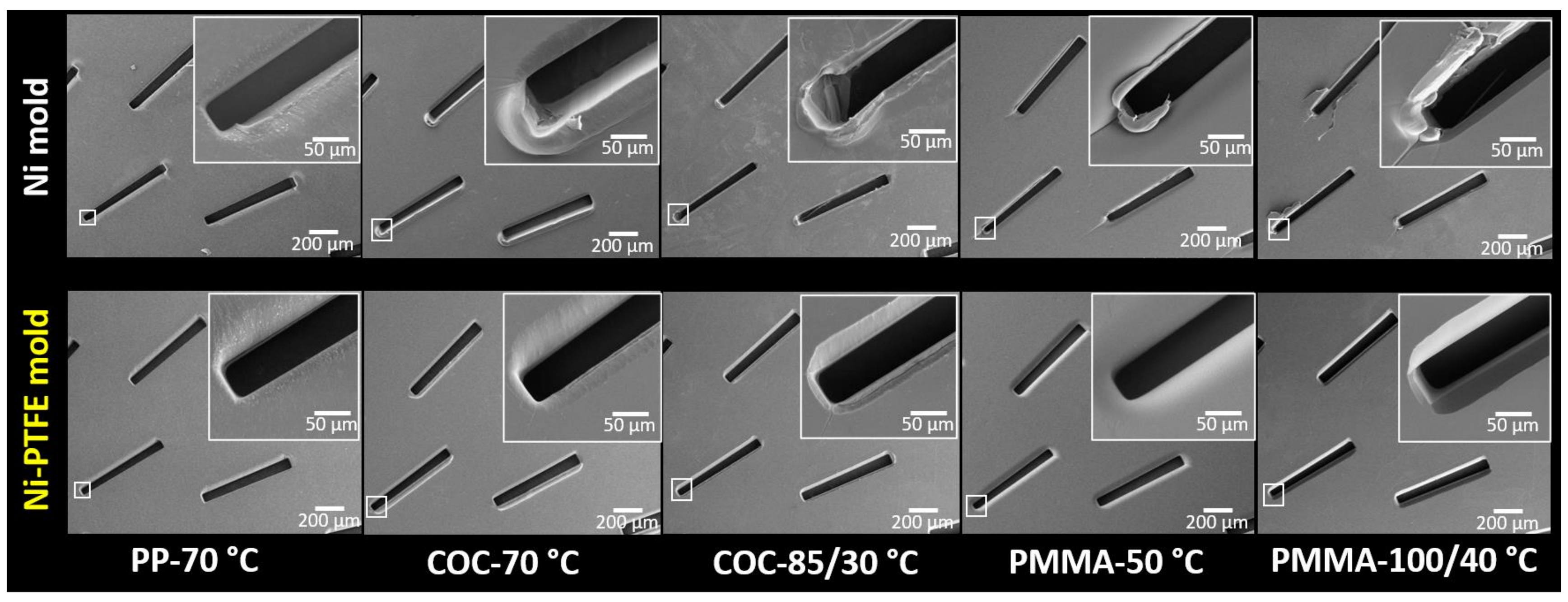


Fig. 3. Surface morphology of injection molded PP, COC and PMMA under different mold temperatures.

❖ Demolding force

- Using Ni-PTFE mold can effectively reduce the demolding force under different processing conditions with various polymer materials.

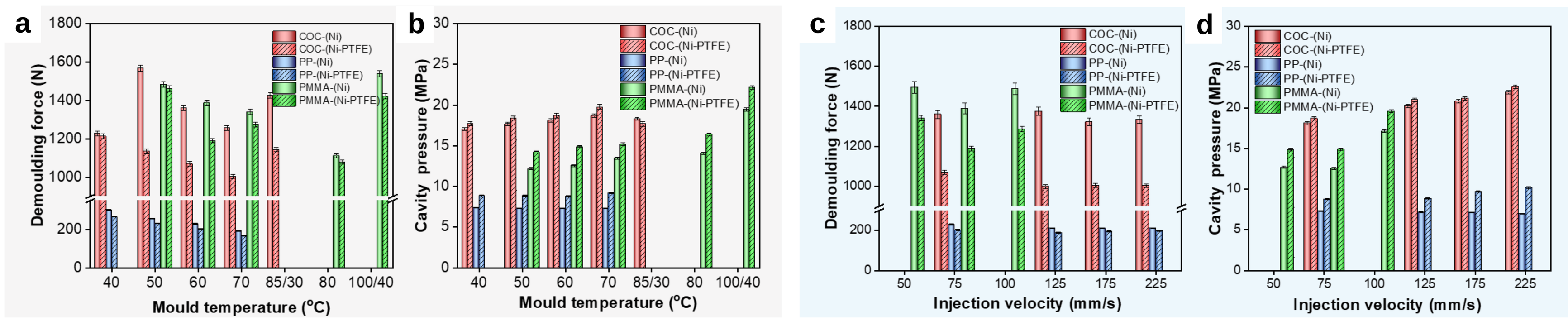


Fig. 4. The relationship between demolding force and cavity pressure with mold temperatures and injection velocities: (a) and (b) under different mold temperatures; (c) and (d) under different injection velocities.

❖ Tribological performance

- After over 1500 cycles of injection molding, Ni mold had broken edges due to its lower wear resistance against polymer material, while Ni-PTFE mold still had intact structure due to its high hardness, low surface roughness, low surface energy and high wear resistance against polymer materials.

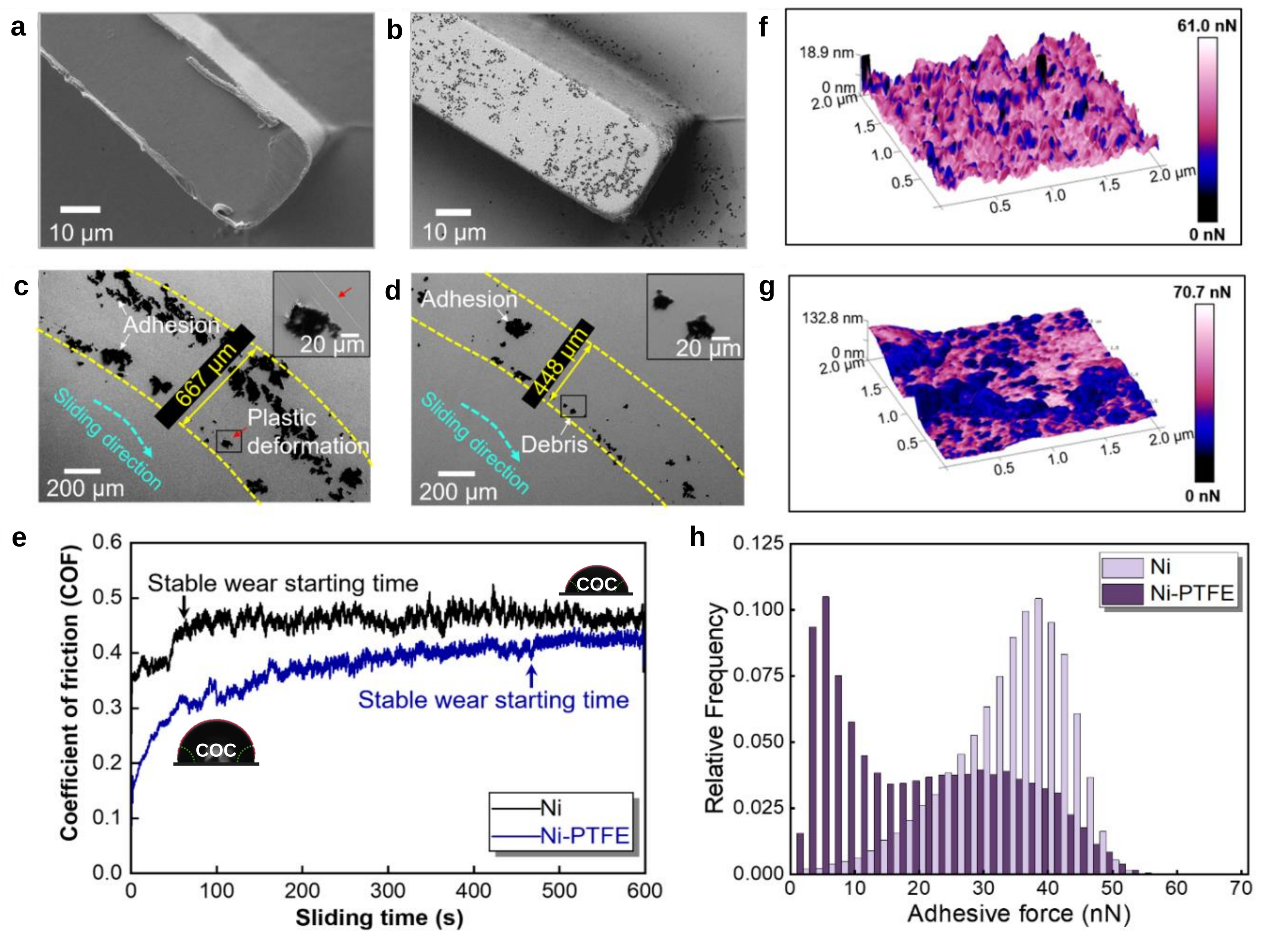


Fig. 5. Surface morphology of the (a) Ni mold and (b) Ni-PTFE mold after injection molding. Wear morphologies on the (c) Ni and (d) Ni-PTFE. (e) COF of two molds against the COC pin. Adhesive force mapping overlayed with surface topography of (f) Ni and (g) Ni-PTFE detected by AFM. (h) The histograms of the adhesive forces distribution.

❖ Cell viability

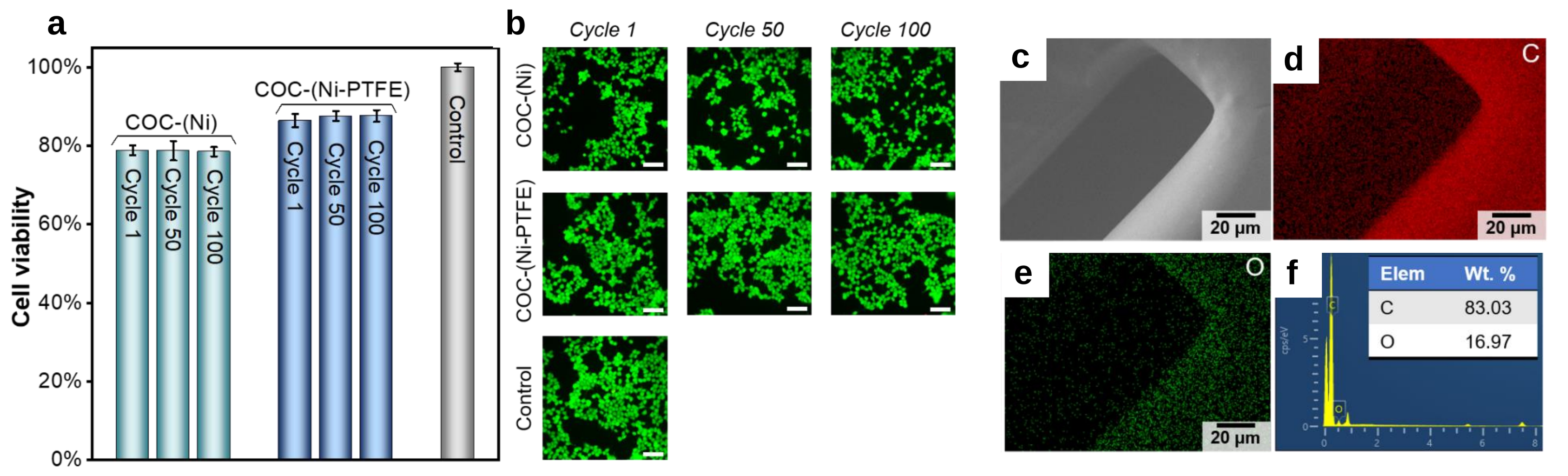


Fig. 6. Cell viability of COC chips demolded from Ni mold and Ni-PTFE mold after 48 h contact (a). Fluorescence microscopy images obtained through live/dead staining (b); Scale bar, 50 µm. (c-f) The weight percentage of elements from the EDS analysis on the COC micro channel produced from the Ni-PTFE mold.

❖ Conclusions

- Ni-PTFE mold was developed based on UV-LIGA and nanoparticle co-deposition aimed at reducing the demolding defects for producing polymer microfluidic chips.
- Such mold showed greatly enhanced microhardness (2.3 times increase), reduced COF (52.2% decrease) and improved hydrophobicity (surface energy of 28.1 mJ/m^2), eliminating the need for surface pre-treatment.
- The non-toxic nature and consistently low surface energy of such mold make it particularly suitable for the large-scale production of microfluidic chips, which can be employed in diverse biological applications.

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