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EFFECT OF POLISHING ON THE FATIGUE RESISTANCE AND RESIDUAL STRESSES FOR THE SHOT PEENED OF 7075-T6 ALUMINUM ALLOY

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Abstract: *Aluminum alloy (7075-T6) is widely used in various industries in parts of aircraft, automobiles and other mechanical applications. It is known that the process of the shot peening leads to an increase in the value of residual stresses, which prolong the fatigue life. However, during surface peening of various metals, including aluminum alloy (7075-T6) used in this work, these surfaces become rough where the places to concentrate the stresses, which will fail when exposed to different dynamic stresses. This paper presents an study on the effect of polishing (the roughness surface induced from shot peening process) on endurance limit and residual stresses result by shot peening. In this paper was used three values of surface roughness (1.5, 3, and 5) µm. The obtained results show that the maximum increasing in endurance limit was (53%) at low roughness compared with as received and increasing value roughly to (27%) compared with alloy after shot peening. . The residual stresses gradually increased (-222.735, -229.602, -250.900) Mpa when the roughness surfaces decreased (5, 3, 1.5) µm respectively.*

Keywords: polishing Shot peening, Residual stress, Endurance limit, Aluminum alloy (7075-T6).

INTRODUCTION

Aluminum alloys are an attractive class of materials because of their high specific static strength. Usually, high static mechanical properties are induced in aluminum alloys by dispersion hardening through solution and ageing heat treatments [1, 2]. Al alloys are frequently subjected to surface treatments in order to improve their plain and notch fatigue strength. Among them, shot peening is one of the most widely used. This process consists of bombarding the component with small spherical shots of a hard material at a relatively high velocity. The multiple indentation of the ductile target surface increases its surface roughness and causes localized plastic deformation, which in turn results in work-hardening and introduction of a in-plane compressive residual stress field in the surface layers [3,4].

Components are regularly subjected to dynamic loads, which make them prone to fatigue failure. It is a well-known fact that almost all fatigue cracks form at the surface due to a variety of surface stress concentration failures. Evidently, the control of surface initiation and growth of cracks is an effective means of enhancing the fatigue endurance of metallic components [5,6]. The results showed that obtained from the positive influence of the shot Peening treatment on the fatigue properties as caused by hardened surface layer and compressive residual stresses delayed the initiation of fatigue cracks. Shot peening treatment nearly doubled the cycles to failure at the higher applied stresses when compared to the untreated specimens [7]. Aggressive shot peening tends to increase the surface roughness which can be detrimental to fatigue performance. The higher roughness creates short crack growth and reduce the fatigue life [8]. The fatigue life reduction factor (LRF) due to the aggressive shot peening was established and empirical relations were proposed to describe the behavior of LRF, roughness and fatigue life [9].

In this paper, the effect of surface polishing of the shot peening aluminum alloy (7075-T6) on the residual stresses and endurance limit is studied. Because the shot peening surfaces of the aluminum alloy lead to the creation of roughness on the surfaces, which generates the concentration of stresses in some rough places, when exposed to dynamic loads will descend the ages of the functionality of these pieces because of the concentration of stresses. The rough surfaces were polished with three different degrees (5, 3 , 1.5µm), and the study of the change of the residual stresses on the surfaces after being polished, as well as the effect of this polishing on the change endurance limit for the selected alloy.

1. EXPERIMENTAL WORK

1.1. MATERIAL

The materials used in this study is 7075-T6 aluminum alloys, low-specific weight and high strength to weight ratio and also high electrical and thermal conductance. This alloy is widely used in industry and in particular in aircraft structure and pressure vessels. The main alloying element in the 7XXX series is Zn, while Mg and Cu are also introduced in order to improve the properties [10]. The chemical analysis of this alloy is in **Table (1)** and the Mechanical Properties is presented in **Table (2)** .

Table 1: Chemical composition of 7075-T6 aluminum alloy.

Percentage Composition	**Si** %	**Fe** %	**Cu** %	**Mn** %	**Mg** %	**Zn** %	**Cr** %	**Ti** %	**Al** %
Nominal [ASM] [11]	0.4 max.	0.5 max.	1.2-2	0.3	2.1-2.9	5.1-6.1	0.18-0.28	0.2	Balance
Measured	0.0167	0.055	1.69	0.011	2.59	5.68	0.217	0.028	Balance

Table 2: Mechanical Properties

Modulus of Elasticity GPa	Hardness, Vickers	Elongation at Break %	Tensile Yield Strength Mpa	Ultimate Tensile Strength MPa
74	152	10.1	483	521

1.2. PREPARATION OF SAMPLES

Two types of specimens were prepared in this study; one for tensile test were prepared according to standards of ASTM E8, see **Figure 1**. And the other is for the fatigue tests were prepared according to machine specifications [12], see **Figure 2**. Specimens manufacturing process was done by using a programmable CNC Milling (C-tek) machine.

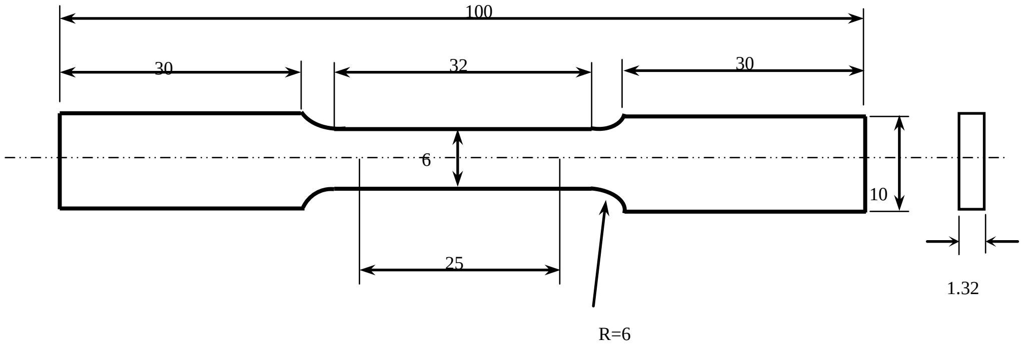

Figure 1: Specimen geometry and dimensions for tensile test (all dimensions in mm) According to ASTM E8.

Figure 2: Specimen geometry and dimensions for fatigue test (all dimensions in mm) According to machine specifications [9].

1.3. SHOT PEENING

The shot peening is accomplished by machine of Sintokogio LTD, model STB-OB. In this machine, the motor rotates an impeller which bombard the shots towards the specimens at 1435 r.p.m motor rotational speed with one jet of shots at an average speed of 70 m/s. The material of the shooting balls is a low carbon steel with average diameter of 1.2 mm and coverage of 80-100 %. The peening machine consist of rotary cylinder with inside diameter of 590 mm and depth of 740 mm in which the specimens is placed. Both tensile and fatigue specimens were subjected to shot peening. The time used for shot peening was (12min), this optimum time for AA 7075-T6 taking from reference [13], see **Figure 3**.

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Figure 3: tensile test specimen and fatigue test specimen after shot peened process.

1.4. POLISHING OF SPECIMENS

After shot peening Process, specimens were prepared using the silicon carbide papers as (200,400, 800) to make three values of surface roughness, they are (5, 3, 1.5) μm respectively, using surface roughness testing machine type DIAVITE DH-7.

1.5. TENSILE TEST

The type of used tensile test machine was microcomputer controlled electronic universal testing machine Tinius Olsen H50KT. Tensile tests were done before and after shot peening and for all stages of the polishing process. Three specimens were tested for each case and taking the average value to satisfy an additional accuracy.

1.6. FATIGUE TEST

The type of fatigue testing machine used in this work was HI-TECH alternating bending fatigue (HSM20) with constant amplitude loading.

A series of tests are commenced by acting a specimen to the stress cycling and the number of cycles to failure is counted. This procedure is repeated on other specimens at progressively decreasing stress amplitudes. As a result, the surfaces of the specimens are under tension and compression stresses when the specimen fluctuated. All the tests done at constant stress amplitude loading with $R = -1$. The obtained data were plotted as stress *S* versus the logarithm of the number *N* of cycles to failure for each of the specimens.

2. RESULTS AND DISCUSSION

2.1. TENSILE TEST RESULTS

To obtain the mechanical properties, the tensile tests of the chosen material 7075-T6 aluminum alloys were performed to obtain the values of the ultimate tensile stress σ_u, yield stress σ_y and elongation E%.

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Table (3) , lists the tensile values for the as received, after shot peening and polishing proses compared to the American Society for Testing and Materials specifications (ASTM) at room temperature.

The results of tensile tests showed that the ultimate tensile strength has a small increasing according to shot peening effect, but the amount of increasing depends on the compressive residual stress and variation with it. The maximum percentage changes of ultimate tensile is (7.485%) for aluminum alloy 7075-T6 polishing for surface roughness (Ra=1.5 μm).

Table 3: Tensile tests results

Alloy type	Condition	σ_u(MPa)	σ_y(MPa)
7075-T6	Standard	573	504
7075-T6	Received	521	483
7075-T6	Shot peening	533	491
7075-T6	Ra=5 μm	545	496
7075-T6	Ra=3 μm	554	501
7075-T6	Ra=1.5 μm	560	506

2.2. S-N CURVE

The S-N curves were obtained from the fatigue tests for all specimens as received, shot peening and polishing process after shot peening at surface roughness Ra (5, 3, 1.5) μm, see **Figures (4,5)** . From these data, the fatigue life estimation equations were obtained, the endurance limit at $N_f=10^6$ cycles.

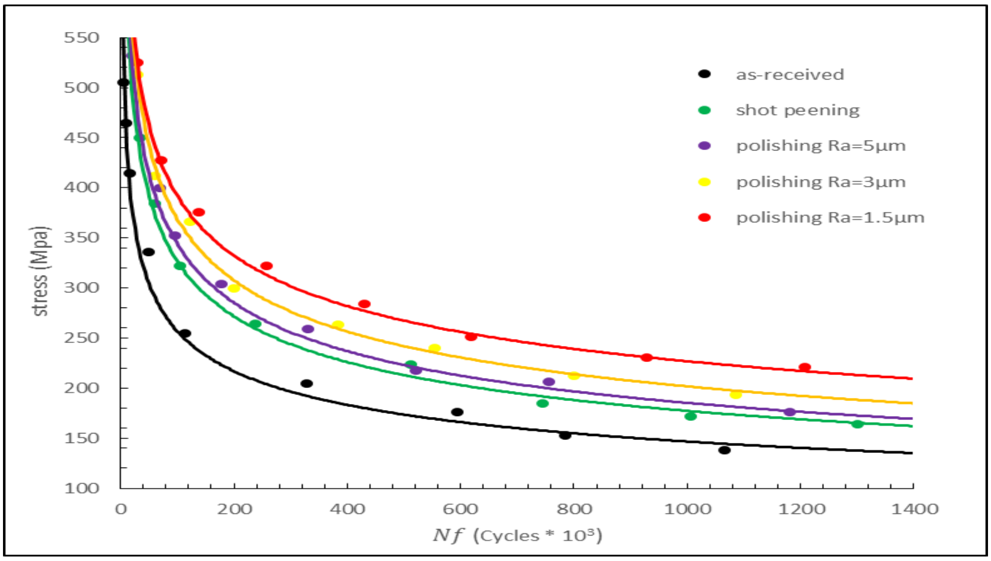

Figure 4: S-N curve for 7075-T6 aluminum alloy.

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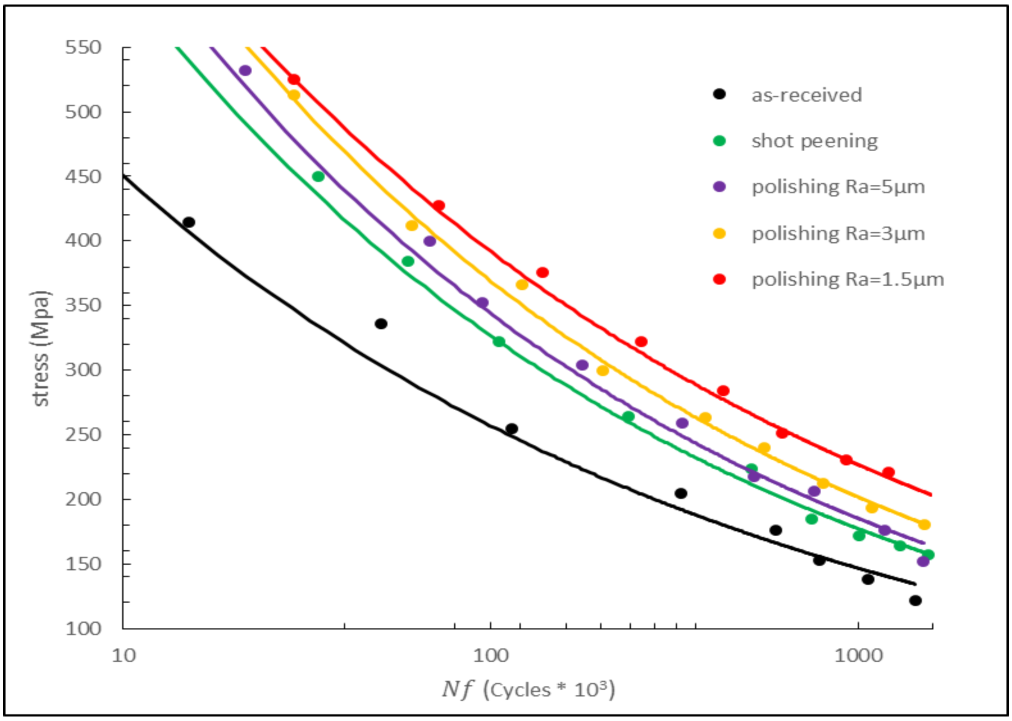

Figure 5: Semi log S-N curve for 7075-T6 aluminum alloy.

From the results of the fatigue test of polishing process (for three stages), it can be observed that the value of the endurance limit of this process is higher than the value of endurance limit of shot peening, that's due to the effect of the compressive residual stresses and roughness surface was decreased.

The equations and fatigue strength which describes this curve are given in **Table (4)**.

Table 4: S-N curved equations for 7075-T6 T6 aluminum alloy.

Condition	Surface roughness Ra(µm)	S-N curve equation	$\sigma_{E.L.}$ (Mpa)	Increase in $\sigma_{E.L.}$ %
Received	Ra=0.19	$\sigma_{E.L.} = 4237.4\, N_f^{-0.243}$	147.6	-
shot peening	Ra=6.093	$\sigma_{E.L.} = 6934.6\, N_f^{-0.265}$	178.25	20.765
Polishing process	Ra=5	$\sigma_{E.L.} = 7553.9 N_f -0.268$	186.28	26.206
	Ra=3	$\sigma_{E.L.} = 7548.6\, N_f -0.262$	202.24	37.02
	Ra=1.5	$\sigma_{E.L.} = 6046\, N_f -0.238$	225.67	52.892

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$\sigma_{E.L.}$-Ra curve of laboratory specimens are presented in **Figure (6)** . The experimental equations of Surface roughness and Endurance limit can be shown in **Table (4)** for polishing process. The relation between Surface roughness and Endurance limit can be described by the formula (1)...

$$\sigma_{E.L.} = 543.52(Ra + 4.316)^{-0.498} \quad (1)$$

From **Figure (6)** , the endurance limit is increasing due to decreased of surface roughness in addition to the presence of residual stresses, the maximum value of endurance limit is (52.892%) at less surface roughness (Ra=1.5 μm).

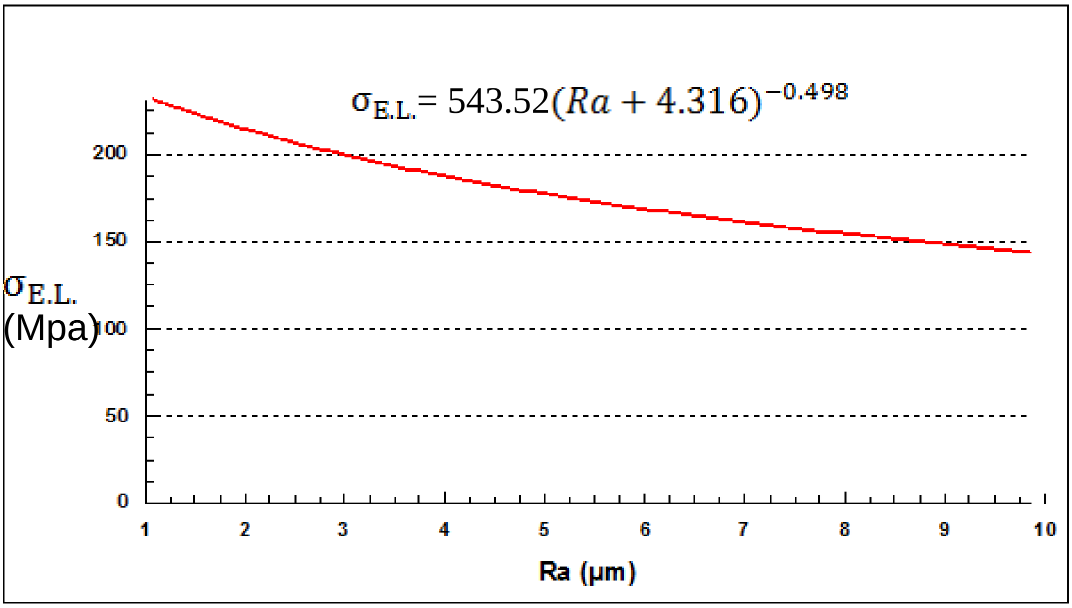

Figure 6: $\sigma_{E.L.}$-Ra curve for polishing process.

2.3. RESIDUAL STRESS

The X-Ray diffraction (XRD) measurements of the residual stress on the surface were taken by using machine type Lab6000, **Figure (7)** , with stress analysis adapter before and after shot peening and polishing process of specimens, the result are shown in the **Table (5**).

σ_{res}-Ra curve of laboratory specimens are presented in **Figure (8)** . The experimental equations of Surface roughness and Residual stress can be shown in **Table (5)** for polishing process.

The relation between Surface roughness and Residual stress can be described by the formula (2)…

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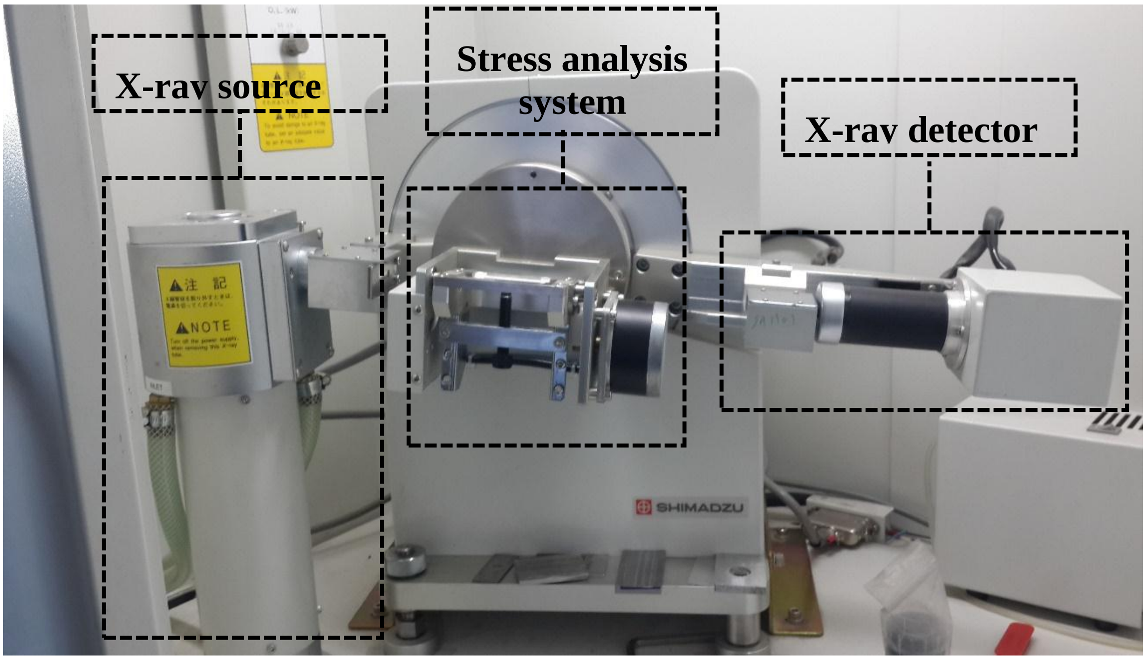

(A)

(B)

Figure 7: A- X-ray diffraction (XRD) machine type Lab-6000 **& B-** XRD machine with specialized stress analysis system

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$$\sigma_{res} = \frac{-220.9178}{1-0.3775\,e^{-0.767Ra}} \qquad (2)$$

From **Figure (8)**, the residual stresses gradually increasing when the roughness surfaces decreasing, this shows that the residual stresses are generated by shot peening process at, or just below the surface layer for a certain depth and usually it is higher that on the surface.

Table 5: Experimental residual stresses results for 7075-T6 aluminum alloy.

Condition	Surface roughness Ra(μm)	σ_{res} (Mpa)
Received	Ra=0.19	-3.477
shot peening	Ra=6.093	-263.527
Polishing process	Ra=5	-222.735
	Ra=3	-229.602
	Ra=1.5	-250.900

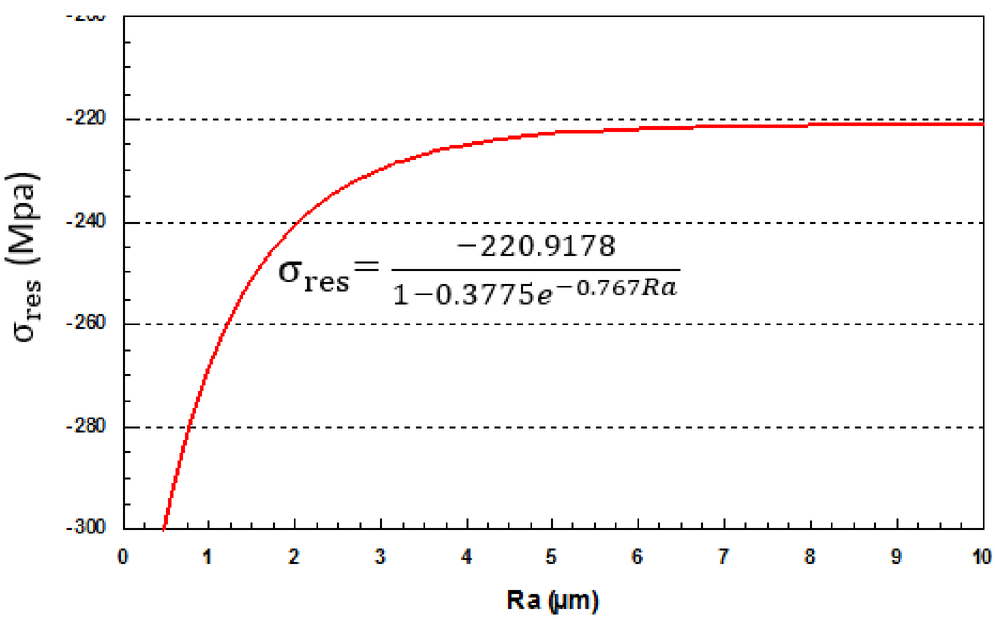

Figure 8: σ_{res}-Ra curve for polishing process

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CONCLUSIONS

The main conclusions drawn from this paper are :

1. After polishing (for less surface roughness Ra=1.5 μm), The maximum enhancement percentage (53%) of the endurance limit was obtained compared with as received material.

2. While the max. improvement carried out of (27%) in the endurance limit at same roughness (Ra=1.5 μm) compared with shot peened specimen.

3. The residual stresses were increased as surface roughness decreased in polishing process.

4. A small improvement obtained in some mechanical properties such as ultimate tensile stress (σ_u) which was (7.485%) compared with as received at high smoothing (Ra =1.5 μm).

5. It was obtained from this study two math. models to calculate the endurance limit & surface roughness and the 2nd model to calculate the residual stresses & surface roughness such as :

$$\sigma_{E.L.} = 543.52(Ra + 4.316)^{-0.498} \quad \& \quad \sigma_{res} = \frac{-220.9178}{1 - 0.3775\, e^{-0.767 Ra}}$$

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