

Ongororo yekupisa nechimiro mukugadzira nekuwedzera simbi pachishandiswa mufano waRosenthal mumamiriro akatsiga

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Pfupiso—Kwemakore akawanda, kwave kune kuedza kwakaitwa mukuvandudza, kuwedzera nekumisikidza mazwi emurongwazivo nehunyanzvi mumutauro weChiShona. Tsvakurudzo iri rinopa mupiro mukuedza uku kuburikidza nekunyora chinyorwa chekutanga chemurongwazivo nehunyanzvi chakanyorwa chose muchiShona, richishandisa mazwi akatovepo pamwe chete nemazwi matsva akavakwa kuti atsanangure pfungwa dzesainzi nehunyanzvi hweKugadzira nekuwedzera simbi (GWS). Pamusoro pekuvandudzwa kwemashandisirwo emutauro weChiShona mumabhuku emurongwazivo, chidzidzo ichi chionoongorora maitiro ezvinhu zvinotariswa pakufananidza kwehwerengedzo yeGWS. Hukama nekudyidzana kuri pakati pehurumidzo yekufamba, simba remagetsi uye tembiricha kunoongororwa, pamwe nemaitiro anoita maparamita aya pakuwanda, chimiro uye kupisa kwedziva resimbi rinonyungudika. Mufano wenhamba wemamiriro akatsiga unogadzirwa uye unoshandiswa kuita ongororo yekugoverwa kwetembiricha uye maitiro edziva resimbi rinonyungudika. Zvawanikwa zvakaradidza tembiricha yepamusoro inodarika 750 °C uye upamhi hwedziva resimbi rinonyunguduka hunosvika 5 mm pa16.1 V ne11 mm/s. Kumanikidzwa kwemukati kunosvika pa -25 MPa panzvimbo inobatanidza chuma nehwaro, ukuwo zviwanikwa zvekuedza ichienderana zvakananyanya nezvakafanotaurwa nemufano. Mutengo wehwerengedzo waive wakaderera, nenguva ye0.98 s pakuongorora kupisa uye 1.36 s pakuongorora chimiro. Chidzidzo ichi nokudaro chinonganisa kuvandudzwa kwemazwi emurongwazivo eChiShona nekushandiswa kwawo mukutsanangura nekuita ongororo yeGWS.

Mazwi ekunanga—kugadzira nekuwedzera simbi; ongororo yehwerengedzo; mufano wehurongwa hwekukwira; ongororo yekupisa; ongororo yechimiro

Thermal and Structural Computational Analysis in Additive Manufacturing of Metals Using the Rosenthal Model under Steady-State Conditions

Abstract—Over several decades, efforts have been made to develop, expand, and systematize scientific and technical vocabulary in chiShona. To the authors' knowledge, the present study represents the first attempt to write a complete scientific research article entirely in chiShona while simultaneously developing and applying chiShona scientific terminology to a contemporary engineering problem. The study combines linguistic and computational objectives by investigating the development and systematic use of scientific terminology and by examining the influence of process parameters on the numerical simulation of Wire Arc Additive Manufacturing (WAAM). Particular attention is given to the relationships and interdependencies among welding speed, voltage, and temperature, as well as their effects on molten-pool characteristics. A steady-state numerical model is developed to investigate the thermal behavior of the WAAM process, and the resulting temperature field is subsequently used as the basis for structural analysis. The results showed a maximum temperature above 750 °C, a molten-pool width of approximately 5 mm at 16.1 V and 11 mm/s, and internal stresses up to -25 MPa. Experimental beads and the welding path closely matched the predicted geometry, while computational times were 0.98 s for thermal and 1.36 s for structural analysis. At the same time, the study demonstrates how established chiShona vocabulary can be combined with systematically developed technical terminology to describe complex concepts in numerical modelling, welding, additive manufacturing, and computational mechanics. The work therefore contributes both to the development of chiShona as a language of scientific communication and to the numerical investigation of WAAM process behavior.

Keywords—additive manufacturing of metal; numerical analysis; hierarchical modelling; thermal analysis; structural analysis

I. NHANGANYAYA

Vakuru vakareva pava-kati: Moyo muti unomera paunoda; sezvo wangu nevashini wakamera pamurongwazivo. Mutsara uyu wakanaka zviku, asi izwi rokuti *murongwazivo* chii? Kupindura mubvunzo uyu nemimwe mibvunzo yakawanda pamusoro pekushandiswa kwemutauro weChiShona, ndizvo zvinoda kuitwa nechinyorwa chino. Mumakore apfuura, vatsvakurudzi vakaedza kugadzira mazwi esainzi muchiShona. Mumwe muenzaniso weizvi i*Duramazwi reUrapi neUtano*, duramazwi reChiShona neChirungu rine mashoko ezvekurapa nehutano rakagadzirwa nechinangwa chekuvandudza kutaurirana pakati pevarapi nevarwere [1]. Mugore ra2015, Madzimbamuto vakanyora nezvemukana wekunyora chinyorwa chesainzi muchiShona. Mubasa ravo, vakaratidza mazwi anogona kushandiswa muzvikamu zvakasiyana zvechinyorwa chesainzi, semuenzaniso: *Abstract* – Pfupiso, *Title* – Musoro, *Introduction* – Nhanganyaya, *Method* – Maitiro, *Results* – Zviwanikwa, *Discussion* – Hurukuro, *Conclusions* – Mhedziso, *References* – Jerero [2]. Nokudaro, zvinoonekwa kuti mazwi nemazwi ehunyanzvi anodiwa pakunyora chinyorwa chesainzi muchiShona atovepo kana kuti anogona kuvakwa pachishandiswa mazwi atovepo mumutauro. Vanyori vakatiwo kuti kuvaka chinyorwa chitsvakurudzo chizere muchiShona kunoda kushanda kwevatsvakurudzi nevanoziva mutauro uye kuchiri chinhu chichaitika mune ramangwana. Mushure mezvo, mugore ra2021, Mabasa, mudzidzi wePhD paRhodes University, vakapedza chitsvakurudzo chedhigirii rePhD chokutanga chakanyorwa chose muchiShona, chine musoro unoti Chave Chemutengure Vhiri Rengoro: Husarungano Nerwendo Rwengano Dzevashona [3]. Zvisinei, kunyora tsvakurudzo yesainzi nehunyanzvi pamwe nekuburitsa zvinyorwa zvesainzi muchiShona zvinoongororwa nevamwe vatsvakurudzi kuchiri kuda kuitwa. Munguva yakatevera, mugore ra2022, Madzimbamuto vakaburitsa chinyorwa chakashandura mazwi efilosofi muchiShona, panguva imwe chete vachiongorora nhoroondo yemaitiro esainzi. [4] Muchinyorwa chakanaka ichi, vachitsanangura pfungwa dzaAristotle, vakaratidza, semuenzaniso, kuti λόγος (logos) inogona kureva izwi, *nature* kureva usikwa uye *research* kureva tsvakurudzo. Vakaratidzawo mashandisirwo akaitwa mazwi echiGiriki kuburikidza nechilatin, semuenzaniso izwi rechiGiriki ὕλη (hyle), raireva sango, iro rakazoshandurwa muchilatin kuva *materia* uye muchiShona kuva munyakwe. Izwi *mathematics*, muchiShona dzidzo yeukamaruswa, rinobva pashoko rokuti μάθημα (mathema), rinoreva kudzidza muchiShona. Pakupedzisira, pfungwa huru yakagadzirwa naAristotle yaiva nzira yekufunga nekuita tsvakurudzo, achisiyanisa zvitendero zvakajairika neruzivo rwakarongeka kureva ἐπιστήμη (episteme), rwakazozivikanwa se *science* muchilatin, rwunonzi ruzivotsetse kana *murongwazivo* muchiShona. Pashure, Mugore ra2023, Mbabvu vakaburitsa mabhuku e Science Kuvana, akanyorwa muchiShona aine chinangwa chekubatsira

vana kudzidza nekunzwisisa pfungwa dzesainzi mumutauro wavo. Mabhuku aya akabatsira mukuwedzera nekusimudzira kushandiswa kwemazwi esainzi muchiShona, achipa mazwi nematsananguriro emazwi ezvidzidzo zvesainzi mumutauro weChiShona. Semienzaniso, mabhuku aya anoshandisa mazwi akadai sekuti zvinhu kureva *matter*, kuyera zvinhu kureva *measurement*, simba kureva *force* kana *energy*, michina kureva *machines*, uye magetsi kureva *electricity* [5]. Naizvozvo, chinyorwa chino chionoenderera mberi nebasa rekutanga chinyorwa chekutanga chemurongwazivo nehunyanzvi chakanyorwa chose muchiShona.

KuGadzira nekuWedzera (GW) kana Additive Manufacturing muchiRungu, inzira yekugadzira chinhu nekuwedzera zvinhu muzvikamu zvakatevedzana, chimwe nechimwe pamusoro pechimwe, kusvikira chinhu chacho chapera. Maitiro aya anogona kushandisa mhando dzakasiyana dzezvinhu, zvinosanganisira simbi, mapurasitiki, ceramics, nezvimwe. Kana zvinhu zvinoshandiswa zviri simbi, nzira iyi inonzi kuGadzira nekuWedzera Simbi (GWS), kana kuti Metal Additive Manufacturing (MAM) muchiRungu. Imwe yenzira dzeGWS ndeyekushandisa magetsi kuwedzera zvinhu muzvikamu zvakatevedzana. Nzira iyi inogona kunzi kubatanidza simbi nekupisa muchiShona, kana kunzi kuwelda, izwi rakatorwa kubva muchiRungu – *welding*. Pachidzidzo chino, tichagadzira rimwe izwi richashandiswa kudana nzira iyi. Ukaonekwa muenzaniso izwi iri mumutauro muchiUkraine, nzira yekubatanidza simbi nekupisa inonzi *зварювання* (zvarivannya), rinobva paizviki rokuti *варути* (varyty), rinoreva *kuvhira* muchiShona. Izwi iri rinotsanangura nenzira iri nyore uye inonzwisika, sezvo richibatanidza pfungwa yekupisa zvinhu kusvikira zvanyungudika nekubatana. Tsananguro dzese dzataurwa pamusoro dzichashandiswa muchinyorwa chino.

Zimbabwe yakambove nyika yaitungamira mukubudirira kwemaindasitiri mudunhu reSub-Saharan Africa, ine zvakwa nemitoo yemabasa yakanyatsogadziwa [6]. Upfumi hweZimbabwe hwainyanya kuvakirwa pakurima nemandasitiri ekugadzira simbi dzakasiyana. Maindasitiri aya ose aishandisa kuwelda nesimbi pamatanho akasiyana, kubva pakushandisa kuri nyore kusvika kune hunyanzvi hwepamusoro. Mugore ra1984, mayunivesiti epolytechnic akanga atotanga kupa dzidzo pamusoro pevhira nesimbi [7]. Maitiro acho aisanganisira kuwelda nemagetsi, semuyenzaniso nzira yekusona Simbi ichishandisa Gasi risingaPindire (SGP) kana Metal Inert Gas muchiRungu. Mazuva ano, kuwelda kuchiri pakati peunyanzvi hunonyanya kudiwa. Mutsvakurudzo yakaitwa neBindura University muna 2024, Kwarteng naMarowa vatsvakurudzi vakaongorora vanhu 400 vanoita basa rekuwelda pamusoro pezvinetso zveutano zvine chekuita nebasa rekuwelda [8]. Mugore rimwe chetero, Tayisepe vakaongorora mashandisirwo esimba pakugadzira nekupedzisa kucheka simbi yeTitanium alloy Ti6Al4V,

vachitarisa kuti chimiro chezvimeu zvinochekwa chinokanganisa sei kushandiswa kwesimba, zvichiridza kuenderera mberi kwekusimukira kwemurongwazivo wesimbi munyika [9].

Mukutsvakurudza uku, GWS harirevi izwi rechiRungu MAM chete, asi rinosanganisirawo nzira yekugadzira nekuwedzera simbi pachishandiswa kuwelda nemagetsi, kana kuti Wire Arc Additive Manufacturing (WAAM) muchiRungu. Mune iyi nzira, simbi iri muchimiro chewaya inonyungudutswa nemagetsi uye yoiswa pamusoro pehwaro kana kuti *substrate*. Basa racho rinoenderera mberi kusvikira chinhu chinodiwa chavakwa. Kugadzira uku kunokurumidza zvikuru, uye kunogona kusvika pakuvaka huwandu hunosvika $500 \text{ m}^3/\text{h}$. [10] Sisitimu yerobhoti inoshandiswa mukugadzira, zvichiita kuti zvikwanisike kuvaka zvinhu zvikuru kwazvo [11]. Imwe yenzira dzakabudirira zvikuru mukugadzira uku inonzi Kufambisa Simbi yeChando (FSC) muchiShona kana Cold Metal Transfer (CMT) muchiRungu. Mune iyi nzira, waya inofamba ichienda mberi nekudzokera shure nekukurumidza, kusvika ka 70 Hz [12], ichidzora moto yemagetsi. Pasinei nezvakanaka zvose izvi, pachine matambudziko aripo, akadai sekusagoverwa zvakaenzana kwakupisa, kupisa kwakawandisa, kushanduka kwechimiro kana *strain*, uye masimba anosara kana rinonzi *residual stress*. Kugadzirisa matambudziko aya zvinogona kushandiswa: maitiro ekutarisisa, kuita otomatiki, uye ongoro yehwerengedzo [13]. Tsvakurudzo inogona kuitwa pamatanho akasiyana, anoti micro, meso, uye macro, uye kazhinji inosanganisira ongoro yekupisa uye ongoro yechimiro. Sezvo ongoro inogona kuva nematanho mazhinji, mutengo wehwerengedzo unogona kuva mukuru zvikuru. Naizvozvo, zvakanakosha kusarudza mufano wakakodzera unomiririra maitiro acho. Kana mufano ukasarudzwa zvisizvo, maitiro acho anogona kutora nguva yakareba uye kushanda zvakashata. Vatsvakurudzi vakawanda vari kuita tsvakurudzo pamusoro peizvi. Morvayová nevamwe, vakashandisa mufano waGoldak [14], ukuwo Mishra naSrivastava vakashandisa mufano weGaussian [15]. Vatsvakurudzi ava vakashandisa mifanidzo iyi kuongorora kupisa nechimiro kunoenderana nenguva, nhorondo yekupisa muchinhu chakagadzirwa, pamwe nemasimba anosara. Zvisinei, pachine mukana wekurerutsa mufano nekuvandudza mutengo wehwerengedzo.

Tsvakurudzo iyi ichashandisa mufano uri nyore uye unoshanda weRosenthal kuita ongoro yekupisa nechimiro mumamiriro akatsiga, pachishandiswa Mufano weHurongwa Hwekukwira Madanho Matatu weAL4043 pasi pemamiriro ezvinhu akarerutswa. Ichazoongororawo mabatiro anoita kumhanya kwekuwelda nevoltage patembiricha uye pakukura kwedziva resimbi rinonyungudika.

II. MAITIRWO

Kugadzira nekuwedzera simbi nemagetsi kunosanganisira kunyungudika nekukurumidza kwewaye yesimbi pasi pesimba guru remagetsi,

kuchiteverwa nekutonhodzwa nekukurumidza kusvikira yaita chimiro chakasimba. Kutu kuongororwa kwemaitiro ekupisa panguva yekuvakwa kwechinhu chakagadzirwa kuitwe, kupisa kunofanira kuongororwa muchuma chekuwelda, kana chinonzi *welding bead*, pamwe chete nehwaro. Nengairo yaRosenthal inopa mhinduro yehwerengedzo yedambudziko rekufambiswa kwakupisa mumamiriro akatsiga, pasi pemafungiro akarerutsa, zvichiita kuti pasave nekudiwa kwekushandisa hwerengedzo yenhamba inodhura. Nengairo Huru Inotonga iyi inogona kuonekwa pazasi [16]:

$$T(x, y, z) = T_0 + \frac{Q}{2\pi k R} \exp \left[-\frac{v(R-x)}{2\alpha} \right] \quad (1)$$

kupi:

$$R = \sqrt{x^2 + y^2 + z^2} \quad (2)$$

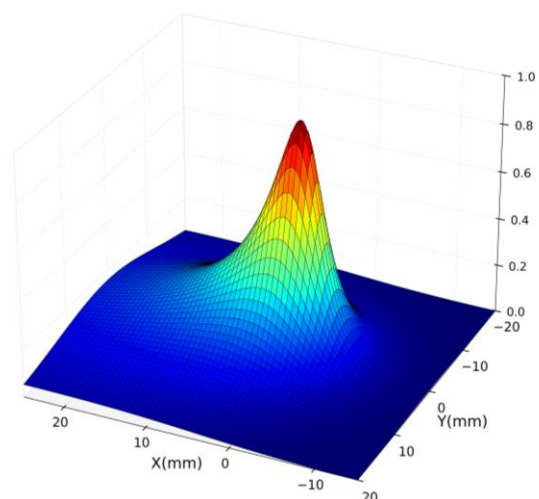
pano T – tembiricha, T_0 – tembiricha yekutanga, x – chinambwe chiri munzira yekufamba kwemoto, y – chinambwe chiri munzira yakatarisana nemufambiro wemoto, z – kudzika kwakupinda kwakupisa muchinhu, R – chinambwe kubva pakati pesimba rekupisa, k – kufambiswa kwakupisa kwechinhu kana *conductivity*, v – uchimbi hwekufamba kwemoto, α – kupararira kwakupisa kwechinhu kana *thermal diffusivity*, uye kunotarwa nengairo iri pazasi:

$$\alpha = k/\rho c_p \quad (3)$$

pano ρ – kuwanda kwechinhu kana *density* uye c_p – huwandu hwakupisa hunodiwa pachinhu kana *specific heat capacity*. Munengairo (1), Q – simba rose rinopinza muchinhu, uye rinoratidzwa nengairo iri pazasi [17]:

$$Q = \eta IV \quad (4)$$

pano I – magetsi, V – *voltage*, inogona kunzi kunetsana, zvichibva pashoko rechiUkraine *напряжение* (napruga), rinoreva *tension* muchiRungu. Rimwe simba remagetsi haripindi muchinhu, richirasika richienda kunharaunda yakapoterredza kana kuva kupisa kunorasika mumoto wekuwelda, inomiririra ne η – kushanda kwakupisa zvakanaka kana *thermal efficiency coefficient*. Mufano waRosenthal wemativi matatu unogona kuonekwa muOnwa 1.



Onwa 1. Mufano waRosenthal wemativi matatu

Mushure mekuwana kugoverwa kwekupisa, unogona kuwanikwa musiyano wekupisa kana *thermal gradient* G , uchiratidza kushanduka kwetembiricha munzvimbo, uye zvinogona kuonekwa pazasi:

$$G = |\nabla T| = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2} \quad (5)$$

Pakutevera, chiyero chekudzikira kwetembiricha kana *cooling rate* chinoverengwa pachishandiswa nengairo inotevera:

$$\dot{T} = -v \frac{\partial T}{\partial x} \quad (6)$$

Izvi zvinoita kuti zvikwanisike kuwana kushanduka kwechimiho kunokonzerwa nekupisa kana *thermal strain*, kunomiririra kuwedzera kwechinhu kunokonzerwa nekukwira kwetembiricha, uye kunotsanangurwa nengairo:

$$\varepsilon_{kps} = \alpha_T (T - T_0) \quad (7)$$

Kana kushanduka kwechimiho kunokonzerwa nekushanduka kwetembiricha kukapfuura muganhu weminama, kana kuti *гнучкість* (gnuchkist) mumutauro weUkraine, inonziwo *elasticity* muchiRungu, kushanduka kwechimiho kwepurastiki kunogona kuitika uye kukonzera masimba anosara. Naizvozvo, kuti iratidzwe pedyo nemamiriro chaiwo, kushanduka kwechimiho kwese kunofanira kusanganisira kushanduka kwechimiho kweminama, kushanduka kwechimiho kwepupisa, uye kushanduka kwechimiho kwepurastiki kana kusingadzoki. Saizvozvo, kushanduka kwechimiho kwese kunogona kuratidzwa nengairo inotevera [18]:

$$\varepsilon_{kwese} = \varepsilon_{kps} + \varepsilon_{nmn} + \varepsilon_{ksg} \quad (8)$$

Pashure hukama huri pakati pekumanikidza kana *stress* nekushanduka kwechimiho hunogona kuratidzwa sezvinotevera:

$$\sigma = D(T) : (\varepsilon_{kwese} - \varepsilon_{ksg} - \varepsilon_{kps}) \quad (9)$$

pano $D(T)$ – inomirira tensor yeminama inoenderana netembiricha. Nengairo iyi inoratidza kuti munda wekumanikidza unoenderana nekushanduka kwechimiho kwepupisa pamwe nekushanduka kwechimiho kwepurastiki, zvichiratidza hukama huri pakati petembiricha nemhinduro yechimiho.

Mutsvakurudzo iyi, maparamita ezvinhu AL4043 akarerutswa akashandiswa, kugona kuona muTable 1.

TABLE I. MAPARAMITA EZVINHU

k (W/m·K)	ρ (kg/m ³)	c_p (J/kg·K)	E (Pa)
156	2690	1230	69e9

Kuti kushanduka kwechimiho kwekusingadzoki kuverengerwe, maparamita ezvinhu anoenderana netembiricha akarerutswa akasarudzwa, uye anoratidzwa muTable 2. Nokuda kwemhedzisiro yakanaka, nengairo ye thermo-elasto-plastic yakarerutswawo pachishandiswa nzira yakarerutswa ye huonekamazwi yeminama nekusingadzoki kufungidzirwa *simplified phenomenological*

elastoplastic approximation, umo Equation 9 inowanwa ne coefficient c .

TABLE II. MAPARAMITA EZVINHU ZVEKUSHANDUKA KWECHIMIHO KWEEKUSINGADZOKI ZVINOENDERANA NETEMBRICHA

100 (°C)	200 (°C)	300 (°C)	550 (°C)
10.4e6 (Pa)	25.6e6 (Pa)	20e6 (Pa)	16.4e6 (Pa)

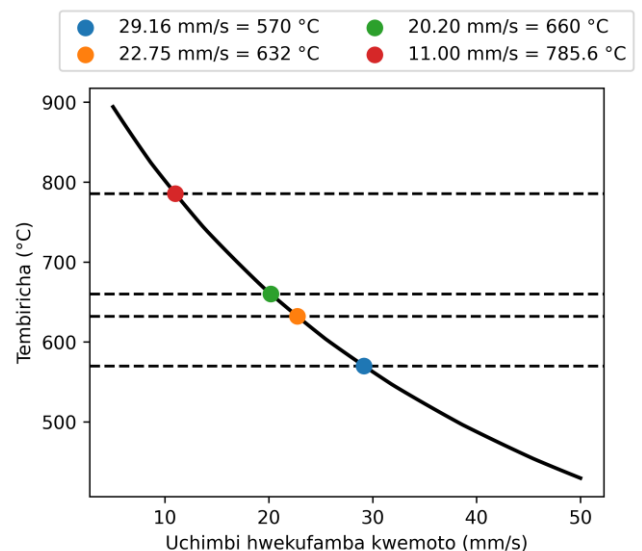
Mufano weHurongwa Hwekukwira Madanho Matatu kana *three-level hierarchical model* unoshandiswa kuderedza nguva yehwerengedzo pakufananidza GWS nemagetsi. Mufano uyu une matanho matatu: danho rekutanga rinonzi rechuma kana *bead*, danho rechipiri rinonzi rerukoko kana *layer*, uye danho rechitatu rinonzi resvingo kana *wall*. Muchidzido chedu, pane chuma chimwe chete chekuvhira, saka panofanira kutariswa danho rimwe chete.

Maparamita ekuwelda akashandiswa muchinyorwa chino ndeaya, magetsi ari $I = 201.0$ A, kunetsana kuri $V = 16.1$ V, uchimbi hwekufamba kwemoto huri $v = 10$ mm/s, uye kushanda kwepupisa zvakanaka kuri $\eta = 0.75$, chihambwe chiri munzira yekufamba kwemoto chiri $x = (-20;50)$ mm, chihambwe chiri munzira yakatarisana nemufambiro wemoto chiri $y = (-25;25)$ mm, kudzika kwepupinda kwepupisa muchinhu kuri $z = 2.5$ mm, tembiricha yekutanga $T_0 = 21.1$ °C. Tembiricha nhatu dzakasazudzwa kuti dziongororwe, 570 °C, 632 °C uye 660 °C, dzichiratidza kubva pachimiho chakasimba kana *solidus* kuenda pachimiho chemvura kana *liquidus*.

Hwerengedzo yose yakaitwa mutsvakurudzo iyi uchishandisa Python neMatplotlib.

III. ZVIWANIKWA UYE HURUKURO (RESULTS AND DISCUSSION)

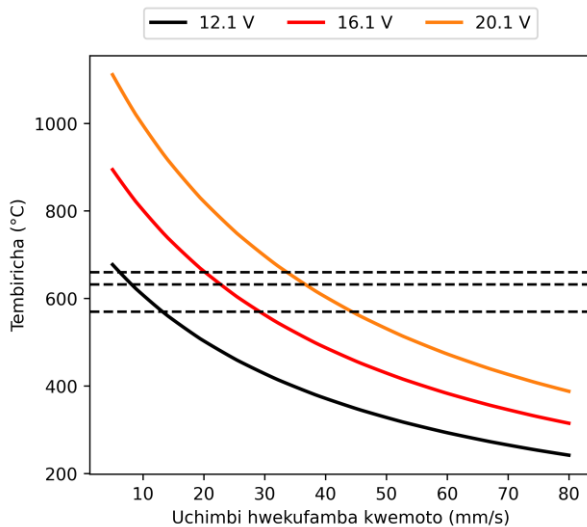
Kutanga, panguva yeongororo, uchimbi hushoma hwekufamba kwemoto hwakaonekwa zvichienderana netembiricha nhatu dzakasiyana dzepachimiho chemvura, sezvinoratidzwa muOnwa 2.



Onwa 2. Uchimbi hwekufamba kwemoto zvichienderana netembiricha nhatu dzakasiyana

Zvaonekwa zvinoratidza kuti uchimbi hwekufamba kwemoto hahufaniri kuderera kupfuura 29.16 mm/s pa $T = 570\text{ }^{\circ}\text{C}$, 22.75 mm/s pa $T = 632\text{ }^{\circ}\text{C}$, uye 20.20 mm/s pa $T = 660\text{ }^{\circ}\text{C}$. Uchimbi hwekufamba kwemoto hwe 11 m/s hwakaongororwawo, uye tembiricha yakawanikwa iri 785.6 $^{\circ}\text{C}$. Nokudaro, kana uchimbi hwekufamba kwemoto huchiderera, tembiricha inokwira.

Hukama huri pakati petembiricha, kunetsana, uye uchimbi hwekufamba kwemoto hwakaongororwawo uye hunoratidzwa muOnwa 3.

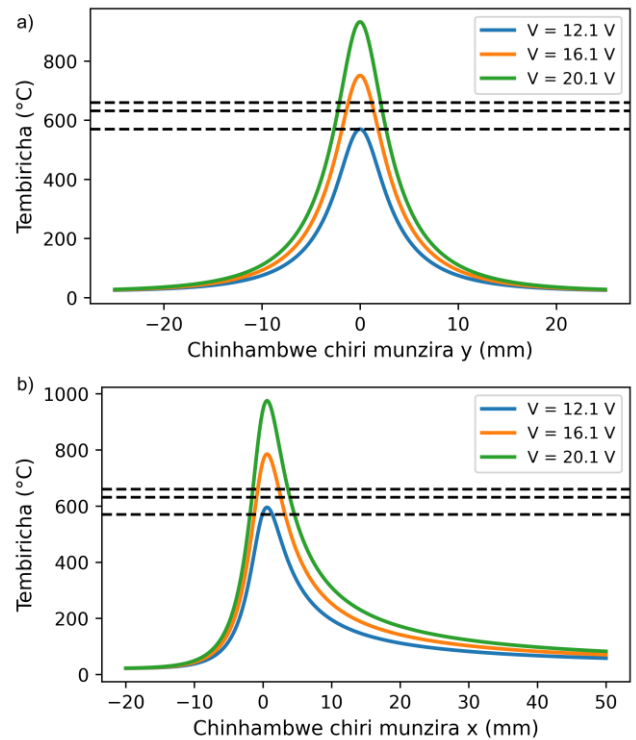


Onwa 3. Hukama huri pakati petembiricha, kunetsana, uye uchimbi hwekufamba kwemoto

Kugona kuona kuti tembiricha yepamusoro inowanikwa pakushandisa voltage yakakwirira pamwe chete neuchimbi hushoma hwekufamba kwemoto. Zvisinei, kana voltage yakakwirira uye uchimbi hwekufamba kwemoto hwaka dererawo, tembiricha inogona kukwira zvakananya uye kupisa zvakananya chinhu chiri kugadzirwa.

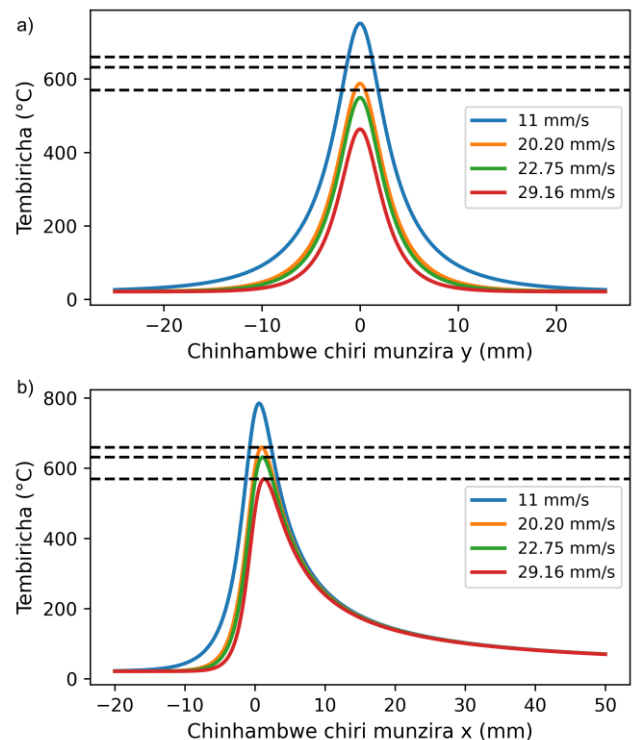
Sezvo tembiricha isina kufanana munzvimbo dzose uye ichiderera kubva pakati, upamhi hwedziva resimbi rinonyunguduka zvinofanira kuongororwawo. Onwa 4 inoratidza hukama huri pakati pedziva resimbi rinonyunguduka nekunetsana. Zvinogona kuonekwa kuti pamavoltage matatu akasiyana, pa 12.1 V tembiricha inomira pa 570 $^{\circ}\text{C}$, izvo zvisina kukwana kuti zvinhu zvacho zvinonyunguduke. Kutu zvinhu zvacho zvisvike pachimiro chemvura, tembiricha inofanira kupfuura tembiricha iyi, sezvinoonekwa pa 16.1 V uye 20.1 V. Zvisinei, 20.1 V inogadzira kupisa kwakananya, izvo zvinogona kukonzera matambudziko uye kupisa zvakananya chinhu chiri kugadzirwa. Nokudaro, 16.1 V inopa tembiricha yakakwana pasina kugadzira kupisa kwakananya. Saizvozvo, 16.1 V ndiyo voltage ine kunaka pakusarudzwa.

Pashure pekudzidza hukama huri pakati pehukuru hwedziva resimbi rinonyunguduka nekunetsana, uye kusarudza voltage kune kunaka, zvino zvinokwanisika kuongorora hukama huri pakati pehukuru hwedziva re-



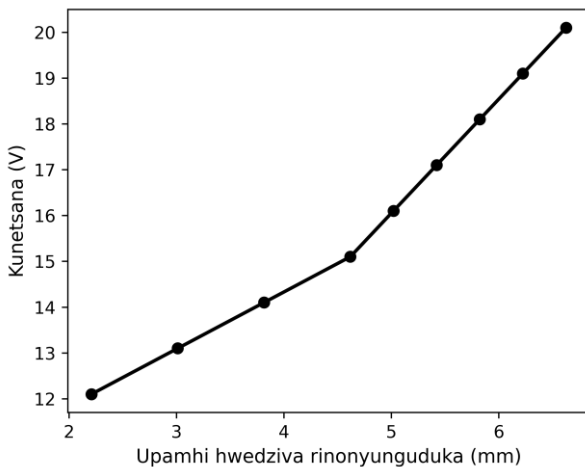
Onwa 4. Hukama huri pakati pehukuru hwedziva rinonyunguduka nekunetsana

simbi rinonyunguduka neuchimbi hwekufamba kwemoto, zvinoratidzwa muOnwa 5. Zvaonekwa zvinoratidza kuti zvinhu zvacho zvinosvika pachimiro chemvura chakazara chete pa 11 mm/s. Uchimbi hwekufamba kwemoto hwakasara hahusviki patembiricha iyi, uye tembiricha inoderera nokukurumidza kana ichibva pakati pesimba rekupisa.



Onwa 5. Hukama huri pakati pehukuru hwedziva rinonyunguduka neuchimbi hwekufamba kwemoto

Pashure pekudzidza hukama huri pakati pehukuru hwedziva rinonyunguduka neuchimbi hwekufamba kwemoto, zvino zvinokwanisika kuongorora hukama huri pakati pekunetsana neupamhi hwedziva rinonyunguduka pauchimbi hwekufamba kwemoto hwakatsiga hwe 11 mm/s, zvinoratidzwa muOnwa 6.

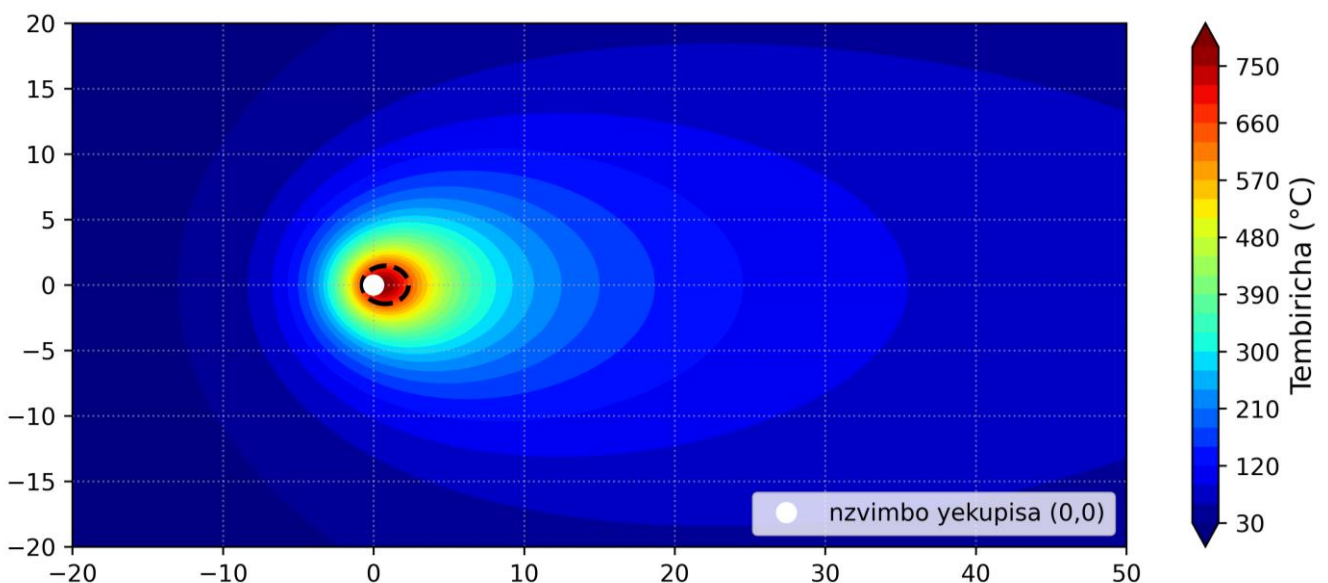


Onwa 6. Hukama huri pakati petembiricha, kunetsana, uye uchimbi hwekufamba kwemoto

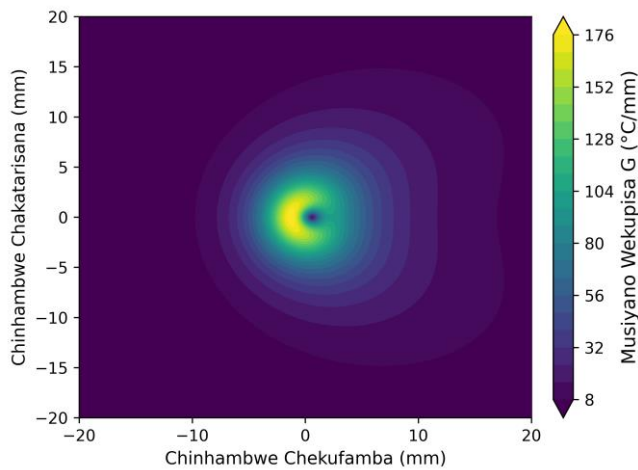
Zvaonekwa zvinoratidza kuti upamhi hwedziva rinonyunguduka hunowedzera kana kunetsana kuchiwedzera. Uyezve, upamhi hwaidiwa hwechuma hwe 5 mm hunowanikwa pa voltage ye 16.1 V.

Pakunge maparamita ose atemerwa, ongororo yakazara yekupisa inogona kutangwa. Onwa 7 unoratidza munda wetembiricha uri mumamiriro akatsiga wakaverengwa pachishandiswa mufano waRosenthal panguva yekufamba kwenzvimbo inopisa muGWS nemagetsi. Munda wetembiricha unoratidzwa kubva pamusoro, uye nzvimbo inopisa iri pedyo ne (0,0). Tembicha yepamusoro, inodarika 750 °C,

inowanikwa pedyo nenzvimbo inopisa uye inodzikira zvisvishoma nezvisvishoma sezvo chinhabwe kubva kunzvimbo inopisa chichiwedzera. Dziva resimbi rinonyunguduka rinoratidzwa nemutsara mutema wakachekwa, umo chinhu chiri pachimiro chemvura Kugoverwa kwetembiricha kunoreba munzira ye x, zvichiratidza kuti kupisa kunopararira zvakananya munzira yekufamba kwenzvimbo inopisa. Pedyo nenzvimbo inopisa pane musiyano wekupisa wakakura, sezvo tembiricha ichiderera nekukurumidza kubva kumatunhu anopfuura 750 °C kuenda kumatunhu ari pakati pe480 ne660 °C. Sezvo chinhabwe chichiwedzera, tembiricha inoderera ichipfuura nematunhu e390, 300, 210 ne120 °C, uye pakupedzisira inoswera kune tembiricha yekutanga inosvika 21.1 °C. Chimiro chemitsetse yetembiricha yakaenzana chinoreba uye chinopararira zvakananya sezvo tembiricha ichiderera, zvichiratidza kupararira wekupisa kubva kunzvimbo inopisa kuenda kunzvimbo dziri kure. Musiyano uyu wekupisa wakakosha pakunzwisa kushanduka kwechimiro wekupisa, kushanduka kwechimiro kwechinhu pakutonhora, uye kukura kwemamasimba anosara muGWS nemagetsi. Nokudaro, zvino zvinokwanisika kuwana kugoverwa kwemusiyano wekupisa G. Onwa 8 inoratidza kugoverwa kwemusiyano wekupisa pedyo nenzvimbo inopisa. Musiyano wekupisa wakakura zvikuwo unowanikwa pedyo nenzvimbo inopisa, uko unosvika panosvika 176 °C/mm. Nzvimbo iyi inoratidzwa nemavara nehuroro uye inomiririra nzvimbo umo tembiricha iri kunoshandisa nekukurumidza pamusoro pechinhabwe chidiki. Sezvo chinhabwe kubva kunzvimbo inopisa chichiwedzera, musiyano wekupisa unoderera zvisvishoma nezvisvishoma. Kugoverwa uku kunoratidza kuti musiyano wekupisa wakanyanya kuungana pedyo nenzvimbo yekupisa, ukuwo nzvimbo dziri kure dzichiratidza shanduko yetembiricha iri diki.

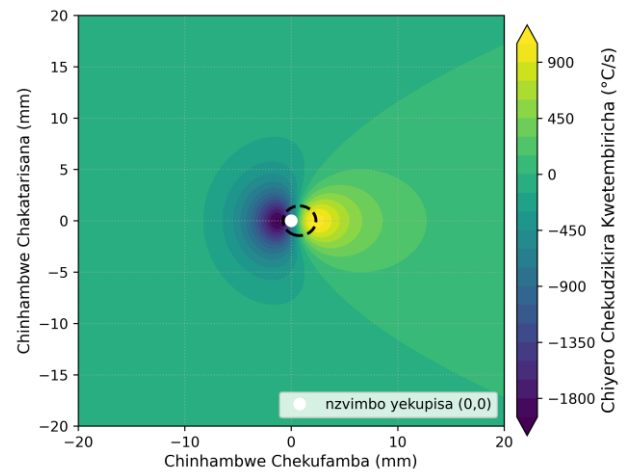


Onwa 7. Munda wekupisa wakaverengwa pachishandiswa mufano waRosenthal mumamiriro akatsiga padanho rekutanga remufano wehurongwa hwekukwira hwematanho matatu weGWS nemagetsi



Onwa 8. Kugoverwa kwemusiyano wekupisa pedyo nenzvimbo yekupisa

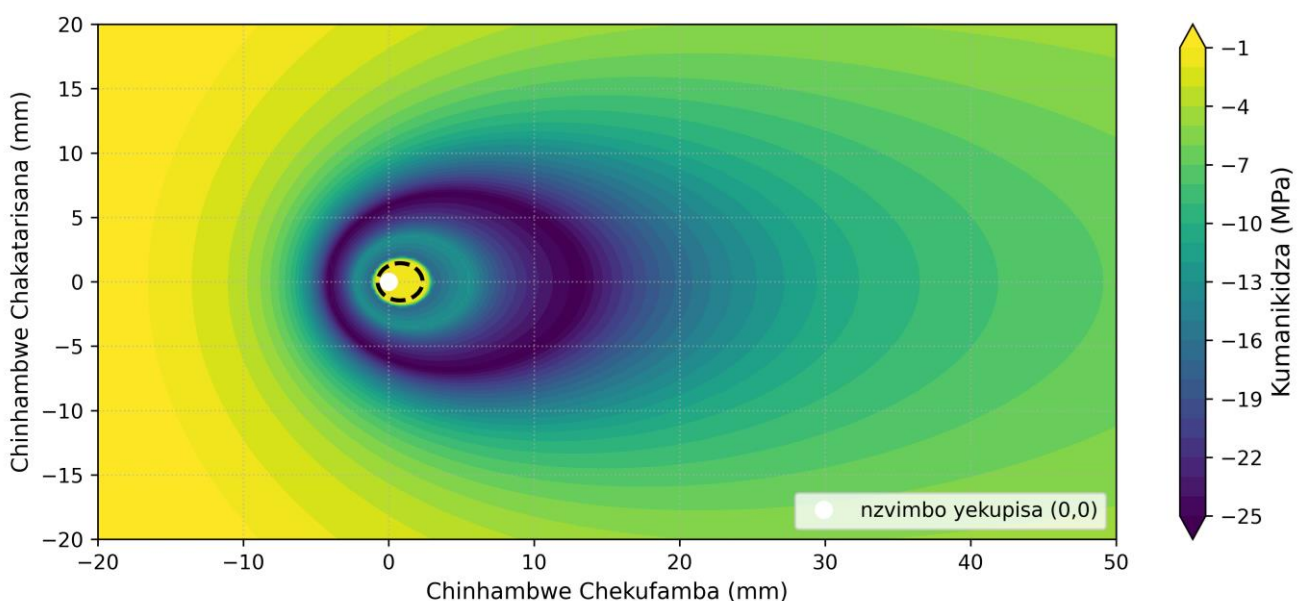
Munda muOnwa 9 unoratidza chiyero chekushanduka kwetembiricha munzvimbo yakatenderedza nzvimbo inopisa muGWS nemagetsi, chinoratidzwa mu $^{\circ}\text{C}/\text{mm}$. Pano kukosha kwakashata kunomirira kuwedzera kwetembiricha, ukuwo kukosha kwakanaka kuchimirira kudzikira kwetembiricha. Nzvimbo yematema iri pedyo nenzvimbo inopisa, ine kukosha kwakaderera kunosvika $-1800^{\circ}\text{C}/\text{mm}$, zvichiratidza nzvimbo ine chiyero chekudziya chakanyanya sezvo nzvimbo inopisa iri kuisa simba muchinhu. Kune rimwe divi, nzvimbo dzhuroro dzine kukosha kunosvika $+900^{\circ}\text{C}/\text{mm}$ dzinomirira chiyero chekudzikira kwetembiricha chakanyanya mushure mekunge nzvimbo inopisa yapfuura. Saka, kugoverwa uku kunoratidza zvakajeka kushanduka kwekudziya nekutondhora kunokonzerwa nekufamba kwenzvimbo inopisa. Pedyo nenzvimbo inopisa nemuganhu uyu, zvinhu zvinopinda nekubuda mumamiriro ekupisa kwakanyanya, zvichiita kuti mamiriro ekupisa ashandu-



Onwa 9. Kugoverwa kwechiyero chekushanduka kwetembiricha

ke nekukurumidza. Kunze kwedziva resimbi rinonyunguduka, chiyero chekushanduka kwetembiricha chinodzikira zvishoma nezvishoma sezvo chinambwe kubva kunzvimbo inopisa chichiwedzera. Izvi zvinoita kuti zvikwanisike kuverenga kushanduka kwechimiro wekupisa. Zvikoshi zvakanikwa zvekushanduka kwechimiro wekupisa, minama, uye kushanduka kwechimiro kwekusingadzoki zvinobva zvaita kuti zvikwanisike kuverenga kumanikidza kwe thermo-elasto-plastic pachishandiswa kufungidzirwa kwehuonekamaizwi.

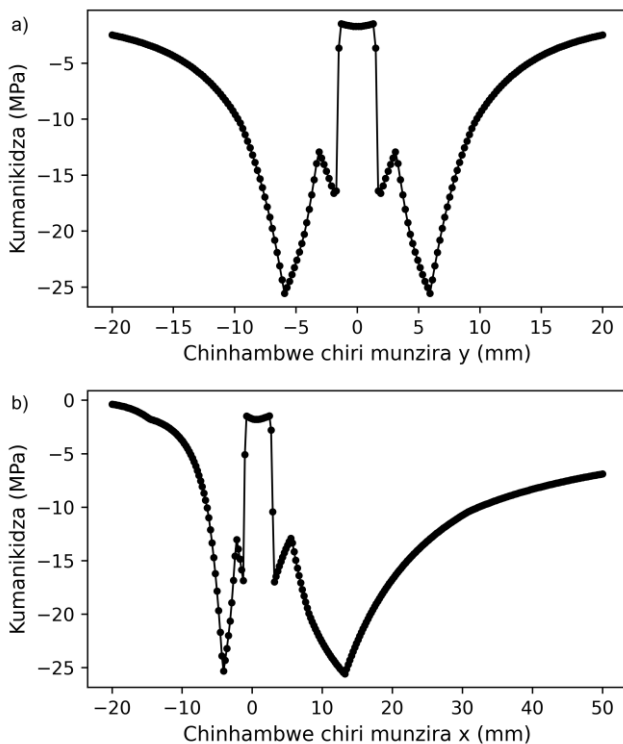
Onwa 10 inoratidza kugoverwa kwekumanikidzwa kwemukati kwechinhu sezviwanikwa zveongororo yechimiro uye sechigumisiro chekupedzisira kwehwerengedzo. Sezvinoratidzwa nechiyero chemavara, kukosha kwekumanikidzwa kunotangira pedyo ne -1 MPa kusvika -25 MPa , uye nekuda kwekuti kukosha kwacho kwakashata, kunoratidza kumanikidzwa kwemukati kwechinhu mumunda wese



Onwa 10. Kugoverwa kwekumanikidzwa kwemukati kwechinhu kwakanikwa panguva yeongororo yechimiro mumamiriro akatsiga padanho rekutanga remufano wehurongwa hwekukwira hwematanho matatu weGWS nemagetsi

uri kuratidzwa. Nzvimbo iri pedyo nenzvimbo inopisa ndiyo ine kumanikidzwa kwakanyanya, inosvika pedyo ne-25 MPa, uye inoratidzwa nemavara akasviba. Izvi zvinoratidza kuti kupisa kwakanyanya pedyo nenzvimbo inopisa kunokonzerwa kushanduka kwechimiwo kwekupisa, ukuwo zvinhu zviri kure uye zvakatonhora zvichirambidza kushanduka uku, zvichigadzira kumanikidzwa kwemukati kwechinhu. Sezvo chinhabwe kubva panzvimbo inopisa chichiwedzera, kukosha kwekumanikidzwa kunoderera zvisvishoma nezvisvishoma kubva pa-25 MPa kuenda kunenge -16, -13, -10 uye pakupedzisira pedyo ne-1 MPa. Chimiwo chemunda wekumanikidzwa chinoratidza kuti kukanganiswa kwekupisa kwakanyanya pedyo nenzvimbo inopisa uye kunoderera zvisvishoma nezvisvishoma kure nayo.

Kuti zvizivikanwe zvakanwanda, zviwanikwa zvakatorwa zvichitevedza nzira dze x ne y , uye zvinoratidzwa muOnwa 11. Kumanikidzwa kwakanyanya kweinege 25 MPa kunowanikwa munzvimbo inobatana nechuma chekuvhira nehwaro, pachinhabwe chinovika 2.5 mm kubva kunzvimbo inopisa, Onwa 11 (a). Munzira ye x , kukosha kwakanyanya kwekumanikidzwa kunowanikwa kure zvisvishoma nenzvimbo inopisa, panenge pa 10 mm, Onwa 11 (b), zvichimirira chimiwo chakareba chinoratidzwa munzira yekufamba kwenzvimbo inopisa uye chinoratidza nzvimbo iri kuiswa chuma. Kuwanikwa kwetsvakurudzo iyi kweongororo yekupisa nechimiwo kunoenderana nemaitiro anotarisirwa echinhu.



Onwa 11. Kumanikidzwa kwechimiwo zvichienderana nechinhambwe munzira dze x ne y

Kushandisa zvaonekwa, kugadzirwa kwechuma chimwe chekuvhira kwakaitwa experimentally,

sezvinoratidzwa muOnwa 12. Pakazogadzirwa machuma matatu ekuvhira uye mugwagwa rekuvhira rimwe, apo upamhi hwechuma hwaive pakati pe4.8–5.2 mm. Uyezve, chimiwo chakawanikwa mukuedza chaienderana zvakanwanda nechimiwo chakafanotaurwa nemufano wenhaba. zvichiratidza kuti nzira iyi inogona kushandiswa zvakanaka mukugadzira neGWS nemagetsi.



Onwa 12. Pakazogadzirwa machuma matatu ekuvhira uye mugwagwa rekuvhira rimwe

Panyaya yemutengo wehwerengedzo, iyi ndiyo imwe yesimba guru remufano waRosenthal, sezvinoratidzwa muTable 3. Kusiiana nemamwe mifano, nguva yehwerengedzo inogona kuverengwa mumasekonzi, nepo nzvimbo yehwerengedzo ichinyanya kutorwa nemifananidzo inogadzirwa, uye isingasviki 2 MB parudzi rumwe norumwe rweongororo. Izvi zvinoratidza kuti mufano uyu unoshanda zviku.

TABLE III. MAPARAMITA EZVINHU ZVEKUSHANDUKA KWECHIMIWO KWEKUSINGADZOKI ZVINOENDERANA NETEMBIRICHA

Ongororo yeKupisa	Ongororo yeChimiro
0.98 sec	1.36 sec
1.68 Mb	1.87 Mb

IV. MHEDZISO

Mutsvakurudzo iyi, mufano waRosenthal pamwe nemufano wehurongwa hwekukwira hwematanho matatu zvakashandiswa kuongorora hukama huri pakati petembiricha, uchimbi hwekufamba kwemoto, nekunetsana, uye kuita ongororo yekupisa nechimiwo, kuongorora munda wetembiricha, dziva resimbi rinonyunguduka, kumanikidzwa kwemukati kwechinhu, uye mutengo wehwerengedzo muGWS nemagetsi. Zviwanikwa zvakaradidza kuti:

- Tembiricha inokwira kana uchimbi hwekufamba kwemoto hwasvikira uye kunetsana kwawedzera. Kana uchimbi hwekufamba kwemoto hwanyanya kukwira, chinhu chinogona kusavika pachimiwo chemvura, ukuwo kana kunetsana kwakakwirira, tembiricha inogona kukwira zvakanwanda uye kukonzera kupisa kwakanwanda. Pasi pemamiriro akaongororwa, 16.1 V uye 11 mm/s ndizvo zvakasazidzwa.

- Ongororo yekupisa yakaratidza kuti tembiricha yepamusoro, inodarika 750 °C, inowanikwa pedyo nenzvimbo inopisa uye inoderera zvisvishoma

nezvishoma sezvo chinhambwe kubva kunzvimbo inopisa chichiwedzera. Dziva resimbi rinonyunguduka rine upamhi hunosvika 5 mm.

- Ongororo yechimiro yakaratidza kuti kumanikidzwa kwemukati kwechinhu kunonyanya kuoneka panzvimbo inobatanidza chuma chesimbi yakaiswa nehwaro, uko kunosvika pa-25 MPa.

- Machuma matatu nemugwagwa wekuvhira zvakagadziwa zvakanikwa mukuedza zvaienderana zvakananyanya nechimiro nehupamhi hwakafanotaurwa nemufano.

- Mufano wakaradidza zvakanaka zvikuru mutengo wehwerengedzo wakaderera kwazvo, nenguva ye 0.98 s pakuongorora kupisa uye 1.36 s pakuongorora chimiro.

Pakazara, zviwanikwa zvakaradidza kuti mufano wakashandiswa wakakwanisa kufanotaura kupisa, chimiro uye zvabuda mukuedza, uchipa mutengo wehwerengedzo wakaderera.

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Duramazwi

Duramazwi remurongwazivo nehunyanzvi akashandiswa mutsvakurudzo iyi

CHISHONA — ENGLISH

chimiro chakasimba — Solidus / Solid State
chimiro chemvura — Liquidus / liquid state
chinyorwa — paper
chiyero chekudzikira kwetembiricha — Cooling rate
chuma chekuwelda — Welding bead
danho rechipiri — rukoko — Layer level
danho rechitatu — svingo — Wall level
danho rekutanga — chuma — Bead level
dzidzo yeukamaruswa — Greek μάθημα (mathema)
 → Latin mathematica → English mathematics —
 Mathematics
GWS nemagetsi — Wire Arc Additive Manufacturing
 (WAAM)
huonekamazwi — Phenomenological / can be seen
 with words
hurukuro — Discussion
huwandu hwekupisa hunodiwa pachinhu —
 Specific heat capacity
hwaro — Base / substrate
hwaro — Substrate
izwi — Greek → λόγος (logos) — Reason / Word
jerero — References
kubatanidza simbi nekupisa — Welding / joining
 metal by heating
kudzidza — Greek μάθημα (mathema) → Latin
 mathematica → English mathematics dzidzo
 yeukamaruswa — Learning
Kufambisa Simbi yeChando (FSC) — Cold Metal
 Transfer (CMT)
kufambiswa kwekupisa kwechinhu — Thermal
 conductivity
kuGadzira nekuWedzera (GW) — Additive
 Manufacturing
KuGadzira nekuWedzera Simbi (GWS) — Metal
 Additive Manufacturing (MAM)
kumanikidza — Stress
kunetsana — Voltage / tension
kunyangudika — to melt
kuongororwa kunoenderana nenguva — Time-
 dependent analysis
kupararira kwekupisa kwechinhu — Thermal
 diffusivity
kushanda kwekupisa zvakanaka — Thermal
 efficiency coefficient
kushanduka kwechimiro — Strain / deformation
kushanduka kwechimiro kusingadzoki — Plastic /
 irreversible - plastic strain - plasticity
kushanduka kwechimiro kwekupisa — Thermal
 strain
kushanduka kwechimiro kweminama — Elastic
 strain — Ukrainian гнучкість (gnuchkist) — English

elasticity / bending — Elasticity
kuvhira / kuwelda — Ukrainian варити (varyty) — to
 boil / heat / melt — to weld
kuwanda kwechinhu — Density
kuwelda / kuvhira — Ukrainian зварювання
 (zvarivannya) — welding — Welding
kuyera zvinhu — Measurement
magetsi — Electricity
maitirwo — Method
masimba anosara — Residual stress
mazwi ekunanga — keywords
mhedziso — Conclusions
michina — Machines
mufano — Model
mufano weHurongwa Hwekukwira Madanho
Matatu — Three-level hierarchical model
munyakwe — Greek ὑλη (hyle) → Latin materia →
 English matter — Matter / Material
munyorori — author
munyorori anonyorerwa — corresponding author
musiyano wekupisa — Thermal gradient
musoro — Title
nhanganyaya — Introduction
nzira yakarerutswa ye huonekamazwi yeminama
nekusingadzoki kufungidzirwa — Simplified
 phenomenological elastoplastic approximation
ongororo — Analysis
ongororo mumamiriro akatsiga — Steady state
 analysis
ongororo yechimiro — Structural analysis
ongororo yehwerengedzo — Numerical analysis
ongororo yekupisa — Thermal analysis
pfupiso — Abstract
ruzivotsetse / murongwazivo — Greek ἐπιστήμη
 (episteme) → Latin science — Knowledge / Science
ruzivotsetse / murongwazivo — Greek ἐπιστήμη
 (episteme) → Latin science — Science / Systematic
 knowledge
simba — Force / energy
tsakurudzo — Research
uchimbi hwekufamba kwemoto — Torch speed
usikwa — Nature
zvinhu — Matter
zviwanikwa — Results

ENGLISH — CHISHONA

- Abstract** — Pfupiso
Additive Manufacturing — kuGadzira nekuWedzera (GW)
Analysis — ongororo
Author — munyori
Base / substrate — hwaro
Bead level — danho rekutanga — chuma
Cold Metal Transfer (CMT) — Kufambisa Simbi yeChando (FSC)
Conclusions — Mhedziso
Cooling rate — chiyoero chekudzikira kwetembiricha
Corresponding author — munyori anonyorerwa
Density — kuwanda kwechinhu
Discussion — Hurukuro
Elasticity / Elastic Strain — kushanduka kwechimiro kweminama — Ukrainian гнучкість (gnuchkist) — English elasticity / bending
Electricity — magetsi
Force / energy — simba
Introduction — Nhanganyaya
Keywords — Mazwi ekunanga
Knowledge / Science — ruzivotsetse / murongwazivo — Greek ἐπιστήμη (episteme) → Latin science
Layer level — danho rechipiri — rukoko
Learning — kudzidza — Greek μάθημα (mathema) → Latin mathematica → English mathematics dzidzo yeukamaruswa
Liquidus / liquid state - chimiro chemvura
Machines — michina
Mathematics — dzidzo yeukamaruswa — Greek μάθημα (mathema) → Latin mathematica → English mathematics
Matter — zvinhu
Matter / Material — munyakwe Greek ὕλη (hyle) → Latin materia → English matter
Measurement — kuyera zvinhu
Melt — kunyungudika
Metal Additive Manufacturing (MAM) — KuGadzira nekuWedzera Simbi (GWS)
Method — Maitirwo
Model — mufano
Nature — usikwa
Numerical analysis — ongororo yehwerengedzo
Paper / Publication — chinyorwa
Phenomenological / can be seen with words — huonekamazwi
Plastic / irreversible - plastic strain - plasticity — kushanduka kwechimiro kusingadzoki
Reason / Word — izwi — Greek → λόγος (logos)
References — jerero
Research — tsakurudzo
Residual stress — masimba anosara
Results — Zviwanikwa
Science / Systematic knowledge — ruzivotsetse / murongwazivo — Greek ἐπιστήμη (episteme) → Latin science
Simplified phenomenological elastoplastic approximation — nzira yakarerutswa ye huonekamazwi yeminama nekusingadzoki kufungidzirwa
Solidus / Solid State — chimiro chakasimba
Specific heat capacity — huwandu hwekupisa hunodiwa pachinhu
Steady state analysis — ongororo mumamiriro akatsiga
Strain / deformation — kushanduka kwechimiro
Stress — kumanikidza
Structural analysis — ongororo yechimiro
Substrate — hwaro
Thermal analysis - ongororo yekupisa
Thermal conductivity — kufambiswa kwekupisa kwechinhu
Thermal diffusivity — kupararira kwekupisa kwechinhu
Thermal efficiency coefficient — kushanda kwekupisa zvakanaka
Thermal gradient — musiyano wekupisa
Thermal strain — kushanduka kwechimiro kwekupisa
Three-level hierarchical model — Mufano weHurongwa Hwekukwira Madanho Matatu
Time-dependent analysis — kuongororwa kunoenderana nenguva
Title — Musoro
Torch speed — uchimbi hwekufamba kwemoto
Voltage / tension — kunetsana
Wall level — danho rechitatu — svingo
Weld — kuvhira / kuwelda — Ukrainian варити (varyty) — to boil / heat / melt
Welding — kuwelda / kuvhira — Ukrainian зварювання (zvarivannya) — welding
Welding / joining metal by heating — kubatanidza simbi nekupisa
Welding / welding-related process / heating until melted — kuvhira
Welding bead — chuma chekuwelda
Wire Arc Additive Manufacturing (WAAM) — GWS nemagetsi
Word / Reason — izwi — Greek → λόγος (logos)

GREEK → LATIN → ENGLISH → CHISHONA

λόγος (logos) — word / reason — Greek → Latin logicus → English word → izwi

ὕλη (hyle) — matter / material — Greek → Latin materia → English matter → munyakwe

μάθημα (mathema) — learning — Greek → Latina mathematica → English mathematics → dzidzo yeukamaruswa

ἐπιστήμη (episteme) — systematic knowledge/science — Greek → Latin scientia → English science → murongwazivo

UKRAINIAN → ENGLISH → CHISHONA

Зварювання (zvarivannya) — welding — Ukrainian → English welding → kubatanidza simbi nekupisa

Варити (varyty) — to boil / heat / melt / weld — Ukrainian → English to weld / to boil → kuvhira

Напруга (napruga) — Voltage / tension — Ukrainian → English Voltage / tension → kunetsana

Гнучкість (gnuchkist) — elasticity / bending — Ukrainian → English elasticity / ability to be bent → kuminama

SYMBOL — CHISHONA — UKRAINIAN* — ENGLISH

*MAZWI ECHI UKRAINIAN ANOWEDZERWA CHETE PAZVINENGE ZVICHIKODZERA

T — tembiricha — temperature

T_0 — tembiricha yekutanga — initial temperature

x — chinhambwe chiri munzira yekufamba kwemoto — distance in the direction of heat-source travel

y — chinhambwe chiri munzira yakatarisana nemufambiro wemoto — distance transverse to heat-source travel

z — kudzika kwekupinda kwekupisa muchinhu — heat penetration depth

R — chinhambwe kubva pakati pesimba rekupisa

k — kufambiswa kwekupisa kwechinhu — thermal conductivity

ρ — kuwanda kwechinhu — density

c_p — huwandu hwekupisa hunodiwa pachinhu — specific heat capacity

α — kupararira kwekupisa kwechinhu — thermal diffusivity

v — uchimbi hwekufamba kwemoto — heat-source travel speed

I — magetsi — electric current

V — kunetsana — напруга (napruga) — voltage / tension

η — kushanda kwekupisa zvakanaka — thermal efficiency coefficient

Q — simba rose rinopinzwa muchinhu — total heat input

G — musiyano wekupisa — thermal gradient

σ — kumanikidza — stress

ε — kushanduka kwechimiro — strain

ε_{kps} — kushanduka kwechimiro kwekupisa — thermal strain

ε_{mnm} — kushanduka kwechimiro kweminama — elastic strain

ε_{ksg} — kushanduka kwechimiro kwekusingadzoki — plastic strain

$D(T)$ — inomirira tensor yeminama inoenderana netembiricha — temperature dependent elasticity tensor